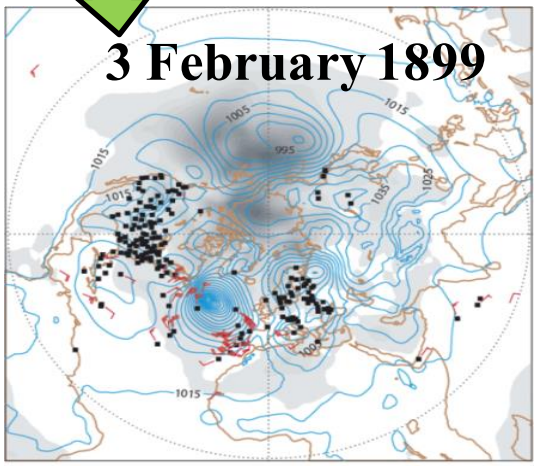
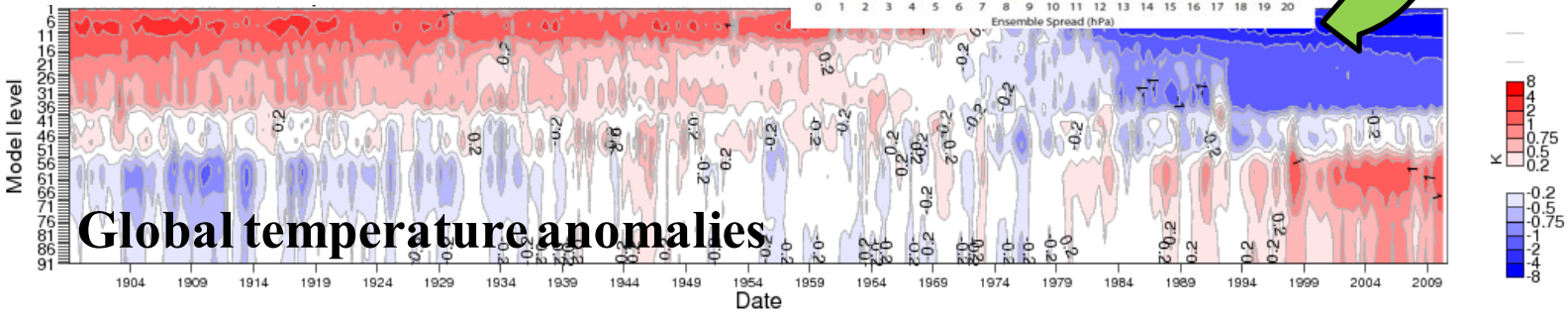
ECMWF ReAnalysis (ERA) Overview

Hans Hersbach, Paul Poli, Dick Dee and reanalysis team



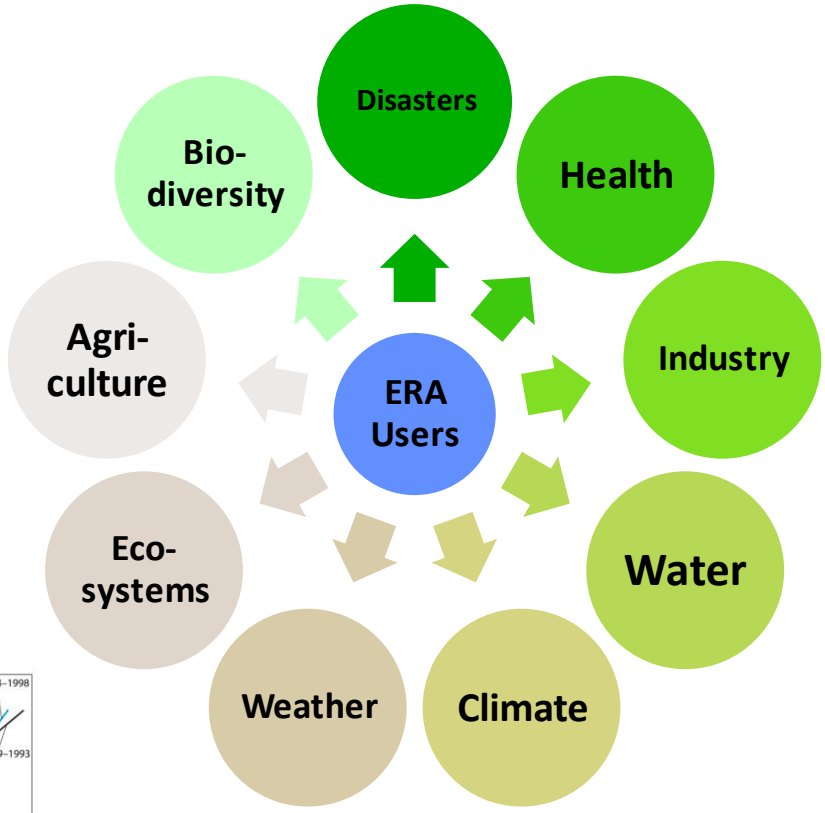


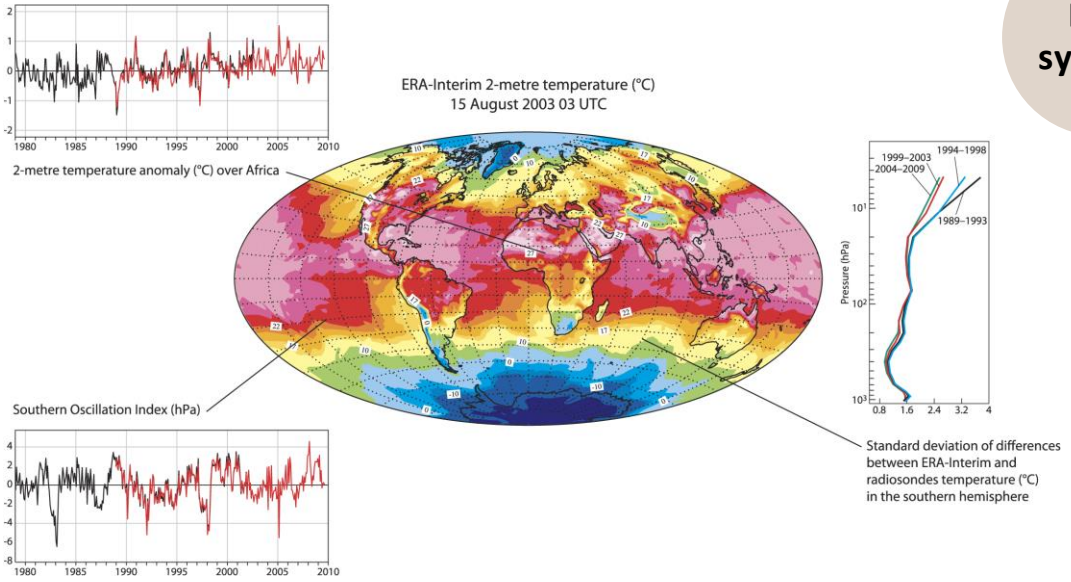
Outline

- *Introduction*
- *ERA-Interim and preparations for its replacement*
- *ERA-CLIM project and century-long reanalyses*
- *ECMWF reanalysis data server*
- *Concluding remarks*

Use of reanalysis data is widespread

- Academic research, model validation
- Downstream modelling applications
- Climate change impact studies
- Assessment of wind energy potential
- Reinsurance risk analysis
- … (more than 20,000 registered external users of ERA data servers)





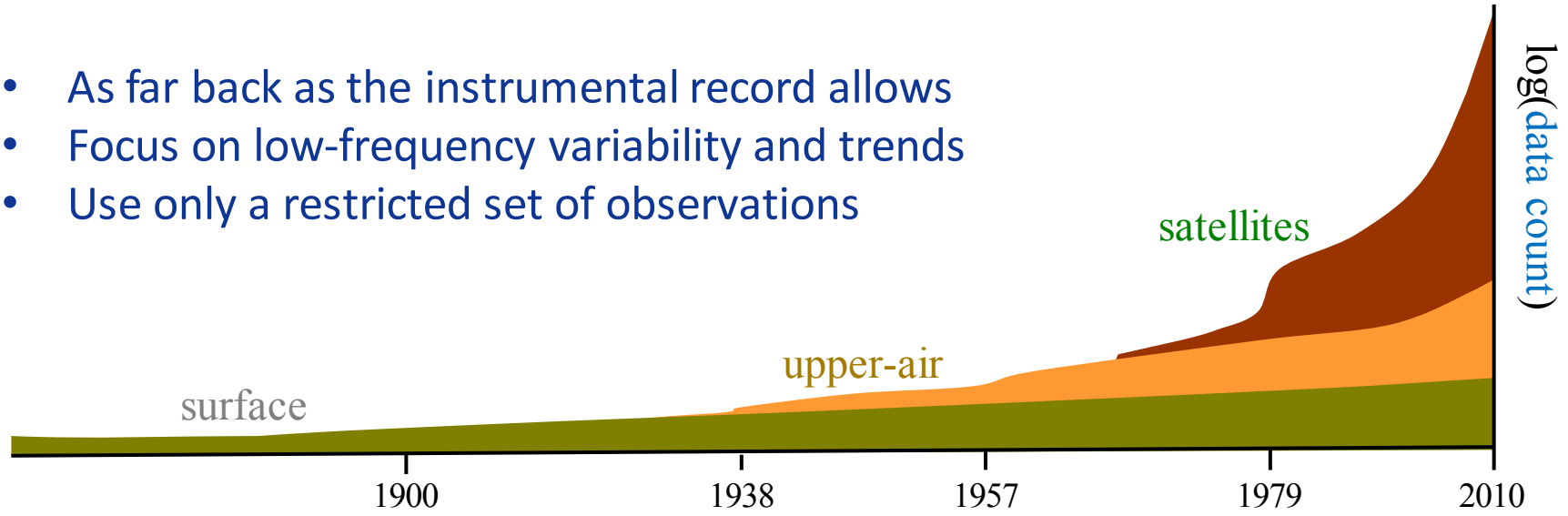
Climate reanalysis: Two types of products

Reanalyses of the modern observing period (~30-50 years):

- Produce the best state estimate at any given time
- Use as many observations as possible, including from satellites
- Closely tied to forecast system development (NWP and seasonal)
- Near-real time product updates

Extended climate reanalyses (~100-200 years):

- As far back as the instrumental record allows
- Focus on low-frequency variability and trends
- Use only a restricted set of observations



Planned reanalysis productions	2012	2013	2014	2015	2016	2017
ERA-Interim ERA-Interim/Land						
ERA-20CM ERA-20C ERA-20C/Land ERA-PreSAT				Extended climate reanalysis		
ERA-SAT ERA-SAT/Land				ERA-Interim replacement		
CERA-20C CERA-20C/Carbon			Coupled with ocean			
CERA-SAT CERA-SAT/Land						

Status of ERA-Interim

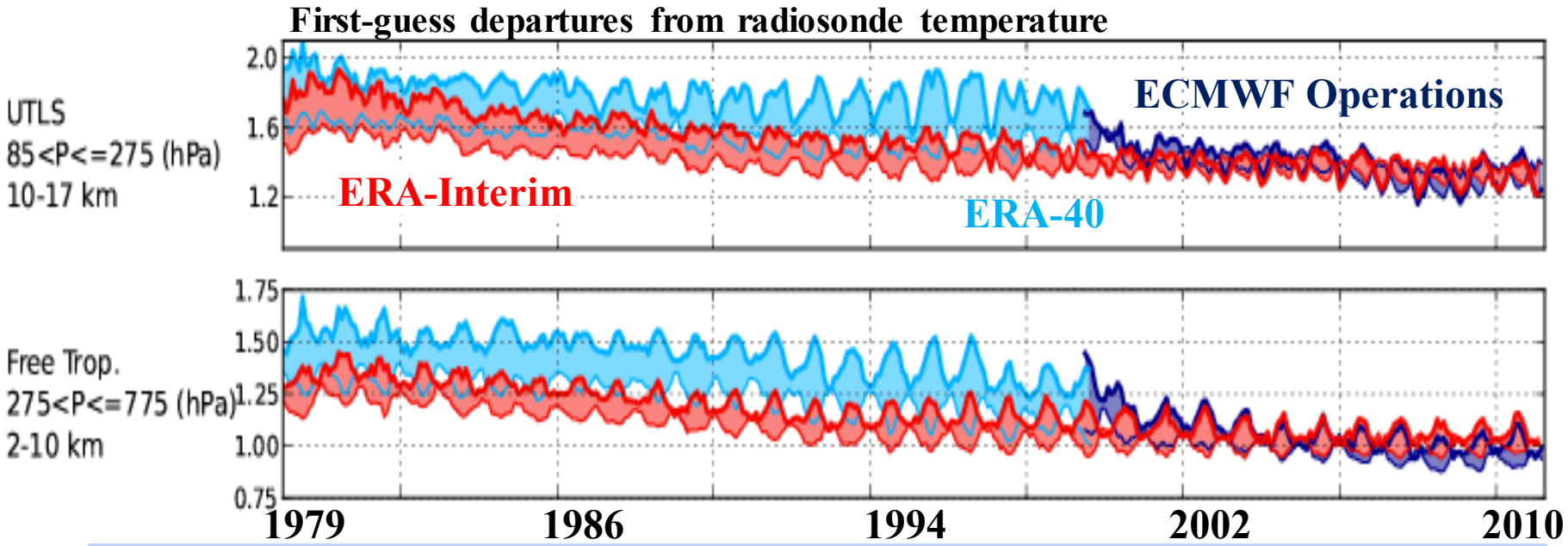
ERA-Interim is a great improvement on ERA-40
Its implementation of **VarBC** was very successful

But is based on a **model cycle from 2007** (Cy31r2), which becomes outdated

- Does not represent a state-of-the-art NWP model anymore
- Cannot ingest new observing systems due to lack of required code

T255 (~80km, and 60 levels) has become very cheap to run:

- need for a resolution upgrade and EDA approach



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Extended climate reanalysis

ERA-Interim replacement

Coupled with ocean

ECMWF

ERA-SAT configuration

- IFS version ***CY40R3 (end 2014)***
- ***Ensemble*** T255L91 ***(~80 km***). Analyses @T95/T159
- High-resolution ***deterministic*** T511L91 (***~40 km***). Analyses @T95/T159
- ***1979-present***, target to produce ***hourly output***
- ***20th century*** SST, sea-ice boundary condition and CMIP5 ***forcing***
- Among other, variational bias correction of ***aircraft data***
- ***Reprocessed / improved datasets:***

  METEOSAT, GOES, GMS, AVHRR NOAA and METOP ***AMV***

  METEOSAT ***radiances***, ASCAT ***sigma0***

  SSMI ***radiances*** (CM-SAF)

  SBUV and TOMS ***ozone*** (NASA v8.6)

  ERS ***soil moisture***

  NCAR ***upper-air in situ*** observations

  Surface pressures (ISPD) and marine reports (ICOADS)

+Various ***observation operator improvements***:

- ✓ Microwave and infrared frequency shifts
- ✓ Time-varying SSU cell pressure
- ✓ Time-varying atmospheric CO2 concentration

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ERA-CLIM pilot reanalyses

Extended climate reanalysis

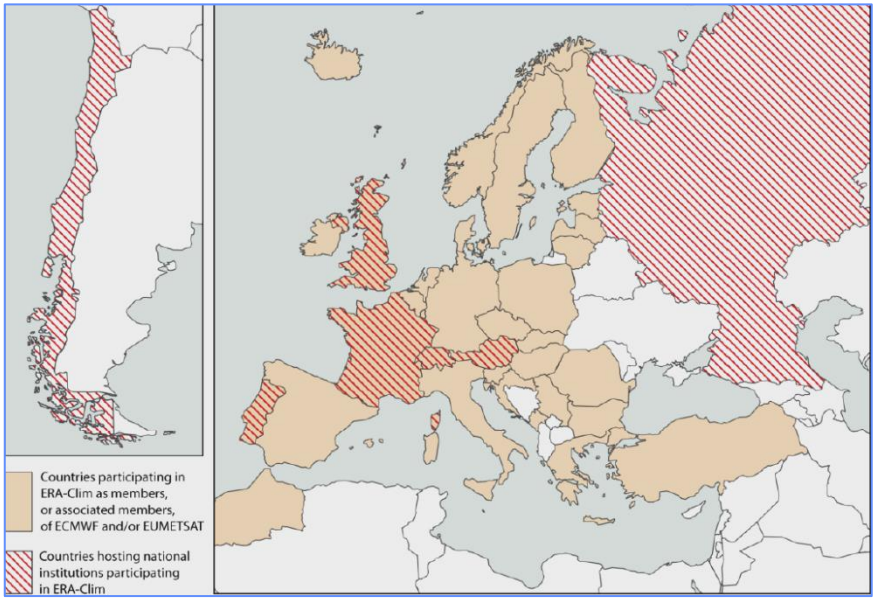
ERA-Interim replacement

Coupled with ocean

ECMWF

The ERA-CLIM project

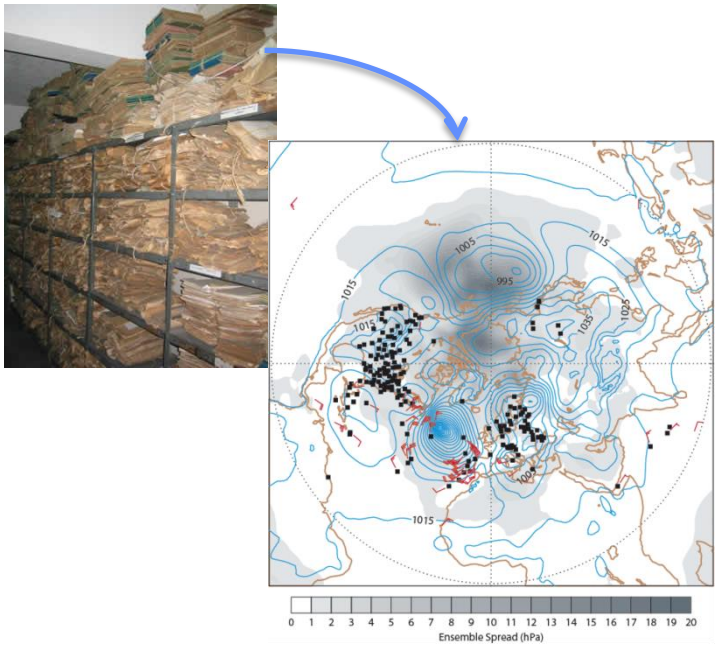
- **ERA-CLIM**: European Reanalysis of Global Climate Observations
- 3-year collaborative research project, 2011-2013
- Within the EU research FP7 programme, Environment theme
- **9 partners, 59 person-years**



Partners:
Met Office,
Météo-France,
EUMETSAT,
Uni Vienna,
Uni Bern,
Uni Lisbon,
RIHMI-WDC (Russia),
UPAC (Chile),
ECMWF

The ERA-CLIM project

Goal: Preparing input observations, model data, and data assimilation systems for a global atmospheric reanalysis of the 20th century



Main components:

1. **Data rescue** efforts (in-situ surface, upper-air)
2. **Atmospheric boundary conditions** (SST, sea ice), forcing data (solar, ozone, aerosols), satellite reprocessing
3. Conducting a number of **20th century pilot reanalyses**
4. Use of **reanalysis feedback** to improve the data record
5. Provide **access** to reanalysis data and observation quality information

Data rescue

Uni Bern, Météo-France, Uni Lisbon, RIHMI, UPAC

One dedicated WP; Led by Uni Bern

Stickler et. al., 2013 (Earth Syst. Data Discuss), 2014 (BAMS)

More than 2.5 Million station days were preserved on more than 450.000 images

- ✓ Organized in a historical climate meta database
- ✓ Four types of data:
  - Surface / upper-air
  - Fixed / moving

About 50% of these were digitized during ERA-CLIM

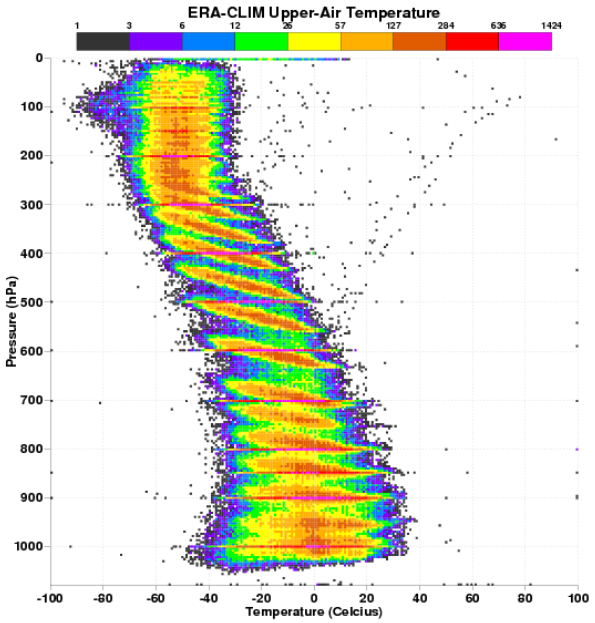
- ✓ Hard work!
- ✓ Common format; similar to CHUAN
- ✓ Priorities:
  - Data sparse regions (poles, tropics, oceans)
  - Early 20th century
  - Long time series
- ✓ Quality control, range checking etc.

This activity is continued in ERA-CLIM2

Data rescue, upper-air data

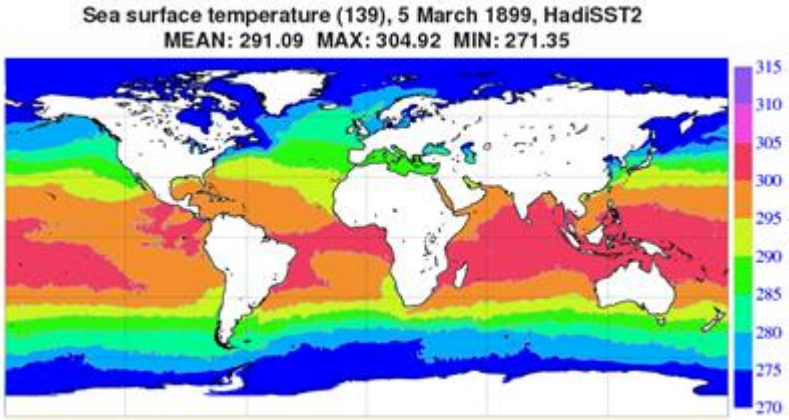
- ✓ **Data will be merged in the next version of CHUAN**
- ✓ **Is available via** http://doi.pangaea.de/10.1594/PANGAEA.821222
- ✓ **Is being used in a pilot reanalysis at ECMWF**

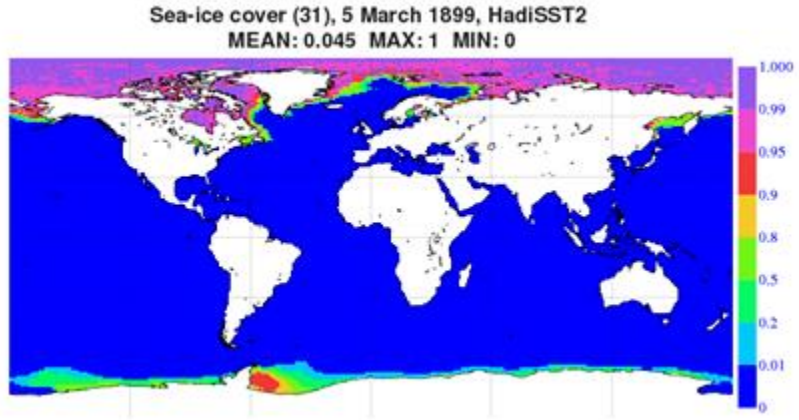
Digitized upper-air data, as available via Pangaea



Temperature recorded on pressure levels

Sea-surface temperature and sea-ice cover: HadISST2

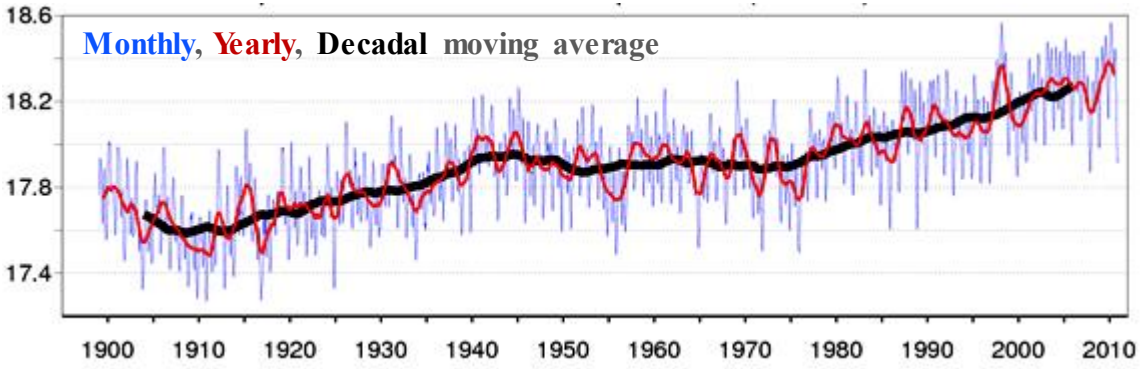




Produced by the ***Hadley Centre*** (follow-up of HadISST1),
Rayner et al. 2013, Kennedy et. al. 2013, Titcher and Rayner 2013

- **1899-2010,** 0.25-degree gridded daily fields
- two releases and two flavours
- Data: in situ ICOADS, Met Office database, AVHRR pathfinder (1985-2007), ATSR2 and AATSR (1995-2011)
- ***Ensemble***: 10 equally likely realizations

- Used in ***all*** ERA-CLIM pilot reanalyses



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ERA-CLIM pilot reanalyses

Extended climate reanalysis

ERA-Interim replacement

Coupled with ocean

ERA-CLIM pilot reanalyses

ERA-20CM, ERA-20C, ERA-20CL, ERA-PreSAT

Conducted at ECMWF

IFS: Coupled atmosphere and ocean-wave components

- ✓ ***All:*** Atm: **T159** (~125km) **91 levels,** WAM: **1.5^{o} , 12 directions**
- ✓ ***Except:*** ERA-20C/Land surface: **T799** (~25km)

Period:

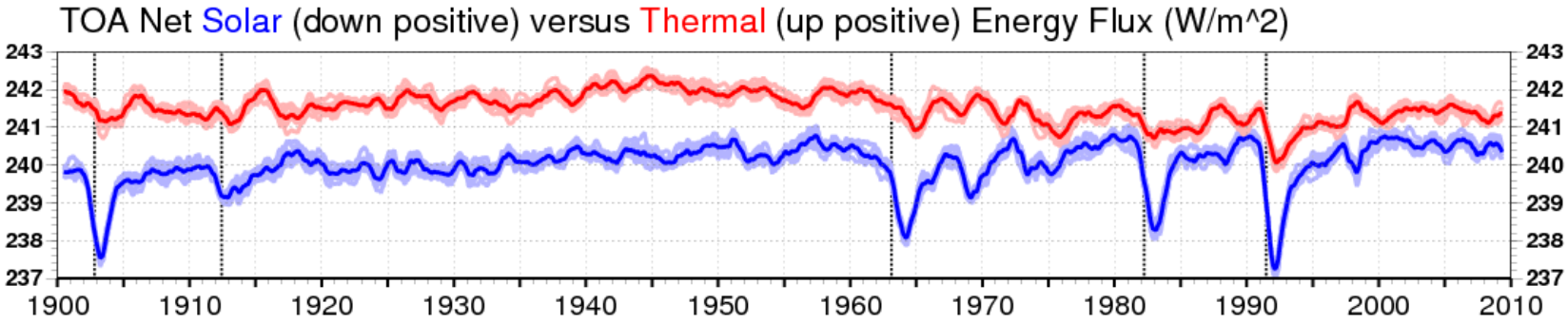
- ✓ ***All:*** **1899 – 2010 and 10-member ensemble**
- ✓ ***Except:*** ERA-PreSAT: **1939-1956+, no ensemble**

All pilot runs use:

- ✓ **HadISST2** SST and sea ice fraction,
- ✓ **CMIP5** long-term forcing for total solar irradiance, ozone, greenhouse gases, aerosols. (synergy with ***EC-EARTH***)

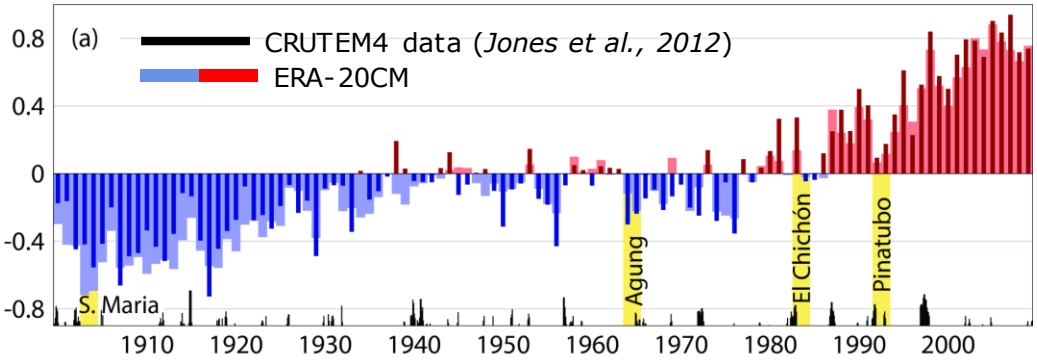
ERA-20CM

(forced model integration, no synoptic data assimilation)



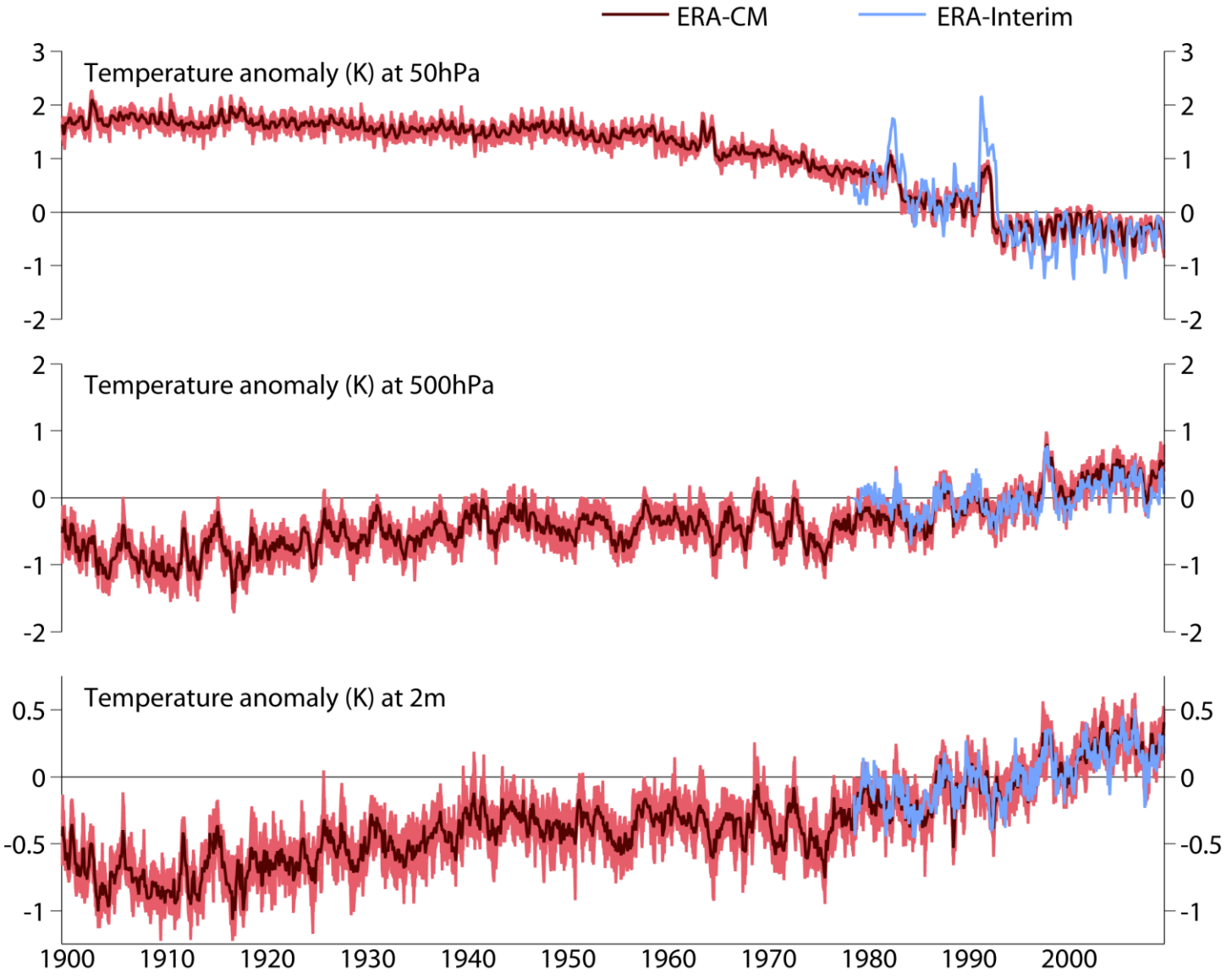
- ✓ Although there are certainly model biases:
- ✓ **ERA-20CM** gives **good** reference of **low-frequency variability**
- ✓ **Well suited** to **project** global warming and major events **onto other geophysical quantities** not directly provided in the forcing data

+ HadISST2



Hersbach, Peubey et. al. 2013, ERA report series (16)

ERA-20CM: Temperature trends + uncertainties



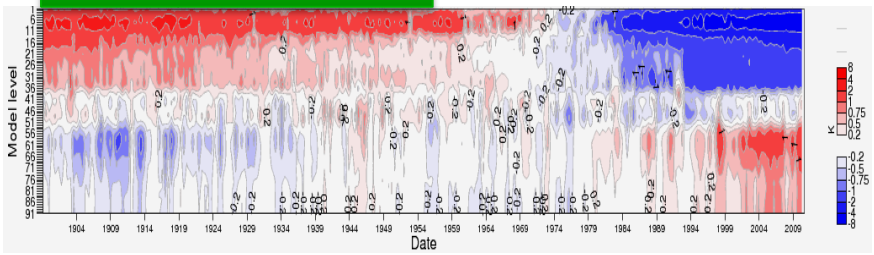
ERA-20C

Poli et. al. 2013, ERA report series (14)

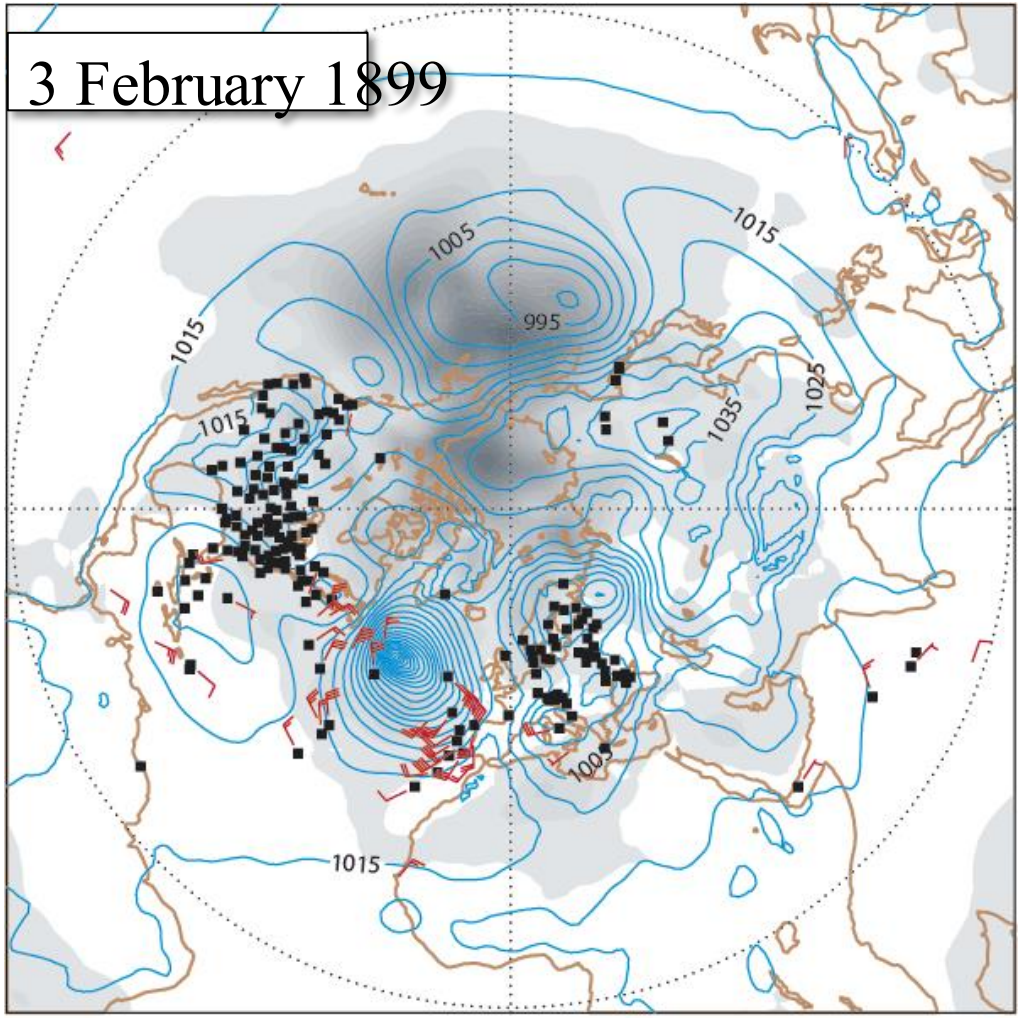
Inspired on the NOAA/CIRES 20CR reanalysis

- ✓ **Usage of synoptic pressure and marine wind** from **ICOADS** and **ISPD** (~1.5 Billion obs)
- ✓ **Variational bias correction** based on ***break-point*** analysis from **20CR** feedback information
- ✓ **Ensemble Data assimilation** of 10 members
  - ➢ Self-updating background error
- ✓ **Deterministic re-run**
  - ➢ Use background info from the ensemble

Temperature trend



ERA-20C: Assimilating surface observations



TERRIFIC STORMS AT SEA

Steamships from All Quarters Report Extremely Rough Voyages.

ALL MORE OR LESS BATTERED

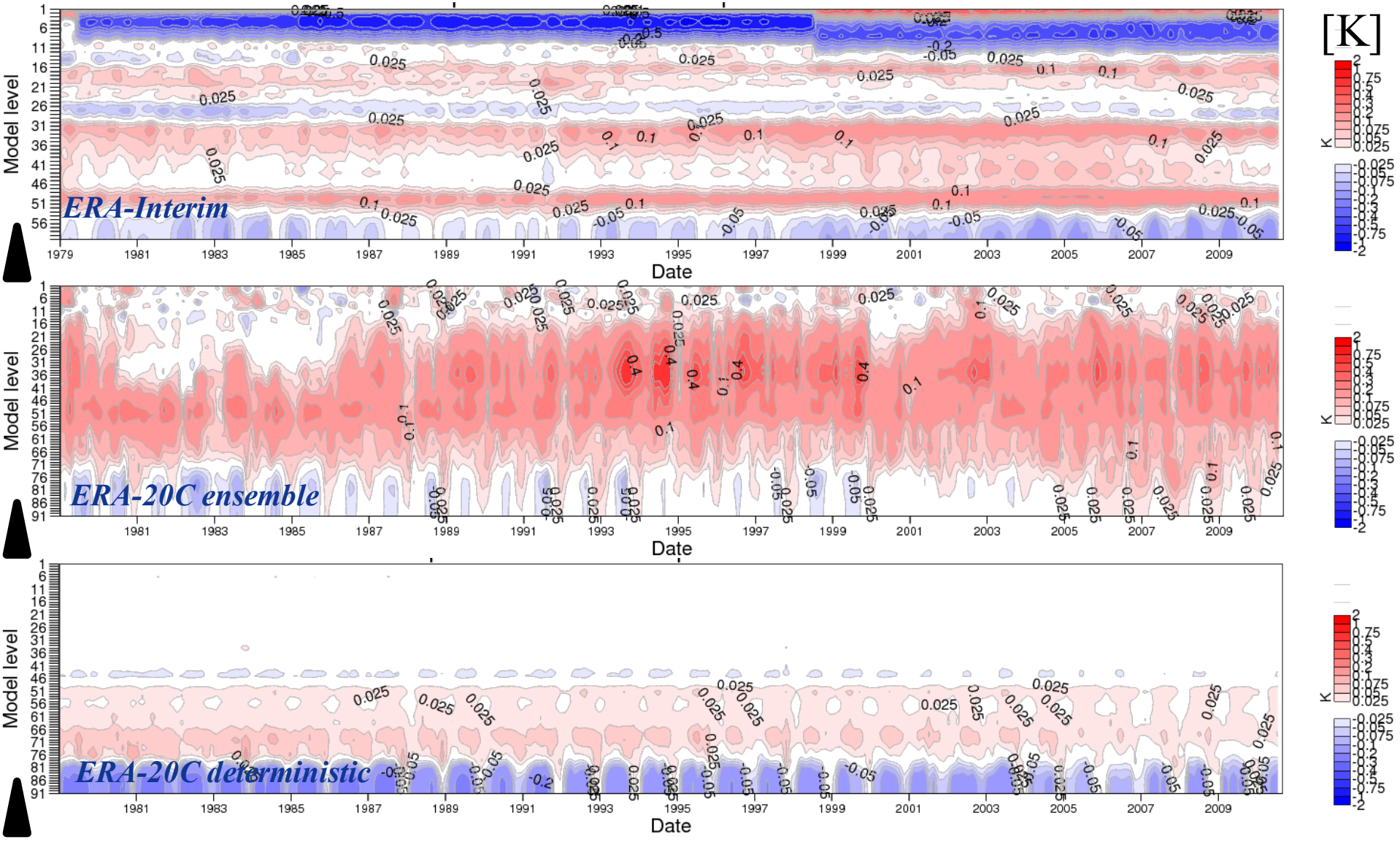
Vessels Sighted in Distress and Abandoned — Blinding Snow and Waves Like Mountains.

All the steamers that came in yesterday were coated with ice from the tops of the masts down to the water line, and all had passed through storms of blinding snow and mountainous waves. The British steamer Ethelgonda, from Bristol and Swansea, which left the latter port on Jan. 19, ran into a gale of hurricane force, and seas swept her decks repeatedly. So fierce was the wind that the boat drifted before the gales and was barely able to keep steerage way. She anchored outside the bar late Sunday afternoon. The cable parted and she lost her anchor, together with 100 fathoms of chain. Then the great snowstorm drove her 150 miles off the shore. She succeeded in getting back late on Tuesday night.

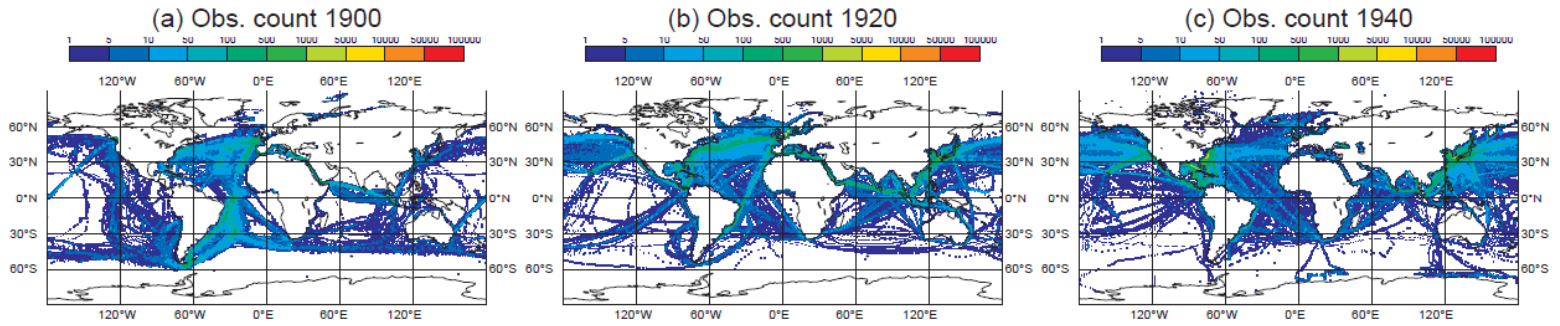
The French liner La Bretagne, from Havre, came in a little before noon yesterday, with 58 cabin and 225 steerage passen-

The New York Times
Published: February 16, 1899

Temperature analysis increments 1979-2010



Surface (vector) wind from ICOADS



Poli et. al. 2013, ERA report series (14)

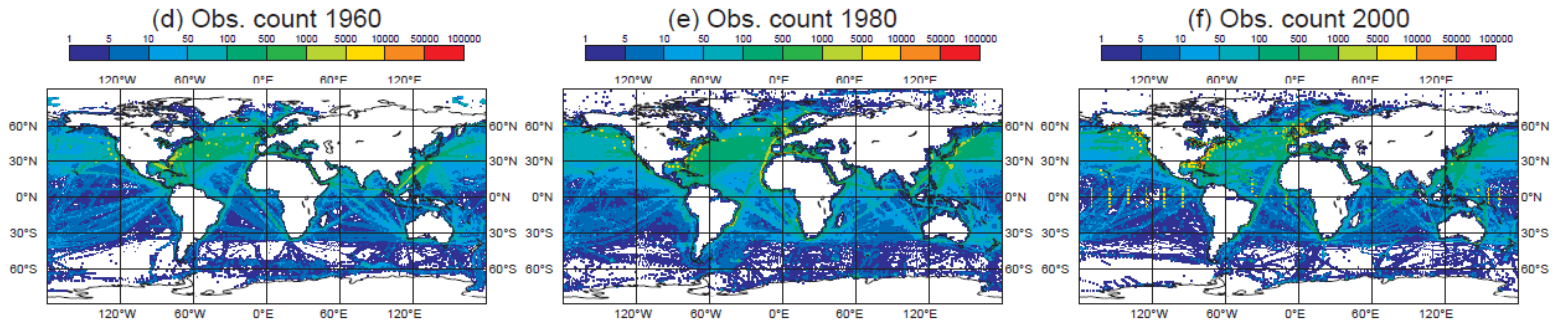
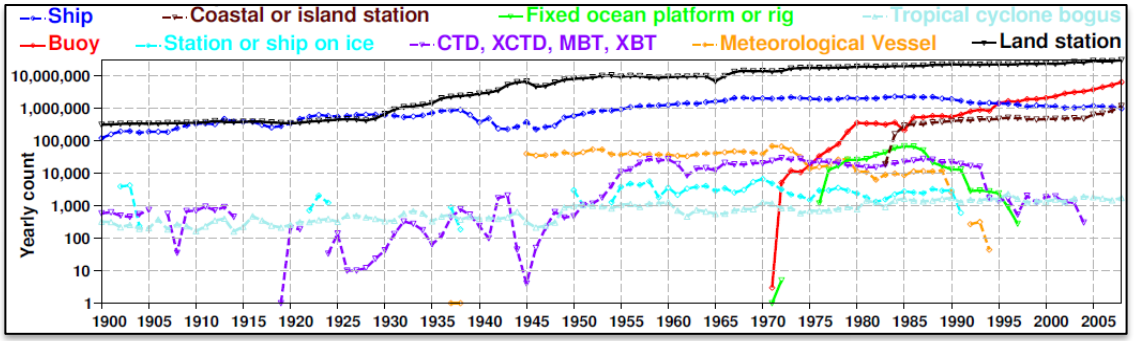
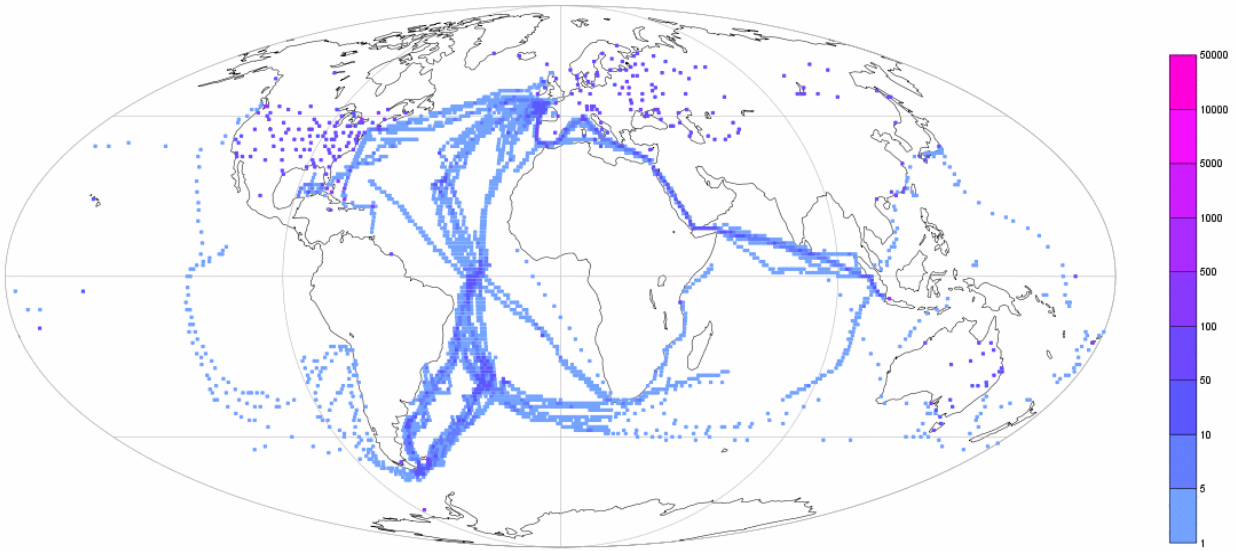


Figure 4: Maps of surface wind vector observation count (from ICOADS 2.5.1), for selected years, in 1° latitude × 1° longitude bins

Surface and MSL Pressure from ICOADS and ISPD



ISPD 3.2.6 and ICOADS 2.5.1 pressure observations assimilated in ERA-20C

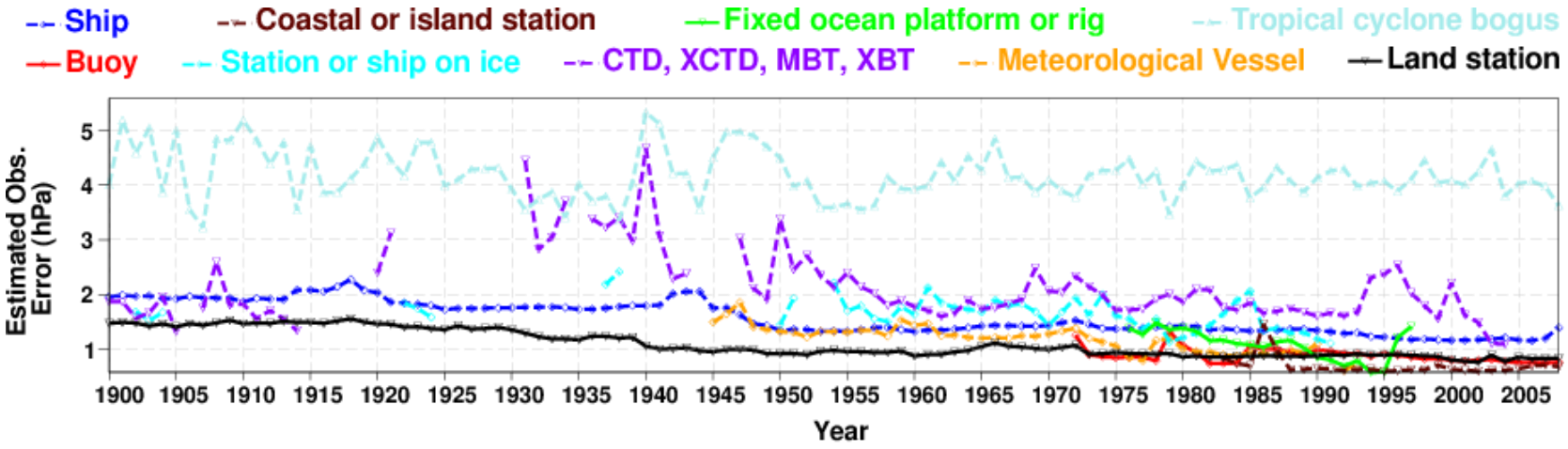


1899

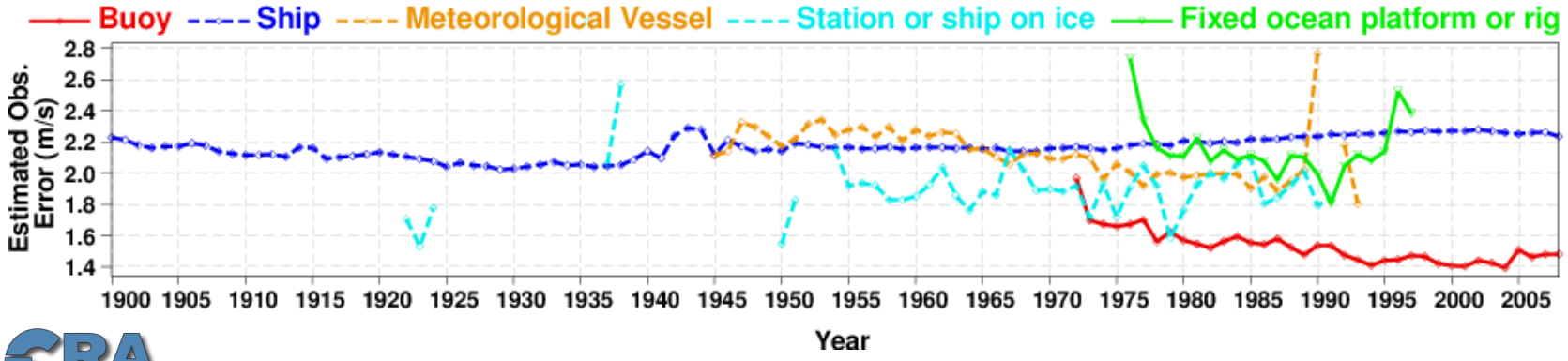
Feedback: estimates on observation error *(Desrosier et. al)*

from (model-obs) departure statistics

Pressure



Wind



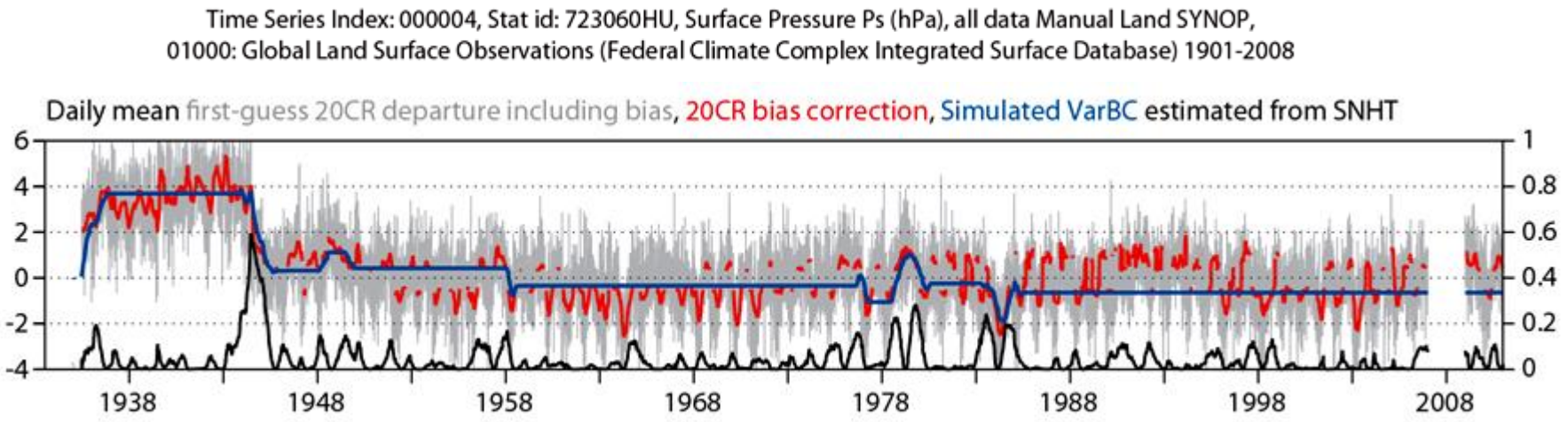
Variational BC using break-point analysis

Perform VarBC on platform level (more than 1 million ships, also tracking issue)

- Has to be rigid; otherwise the signal is taken away from the observations

Build on feedback information from 20CR (ISPD *and* ICOADS)

- detect break points in advance, create quantity: ***bias volatility*** (=normalized SNHT)



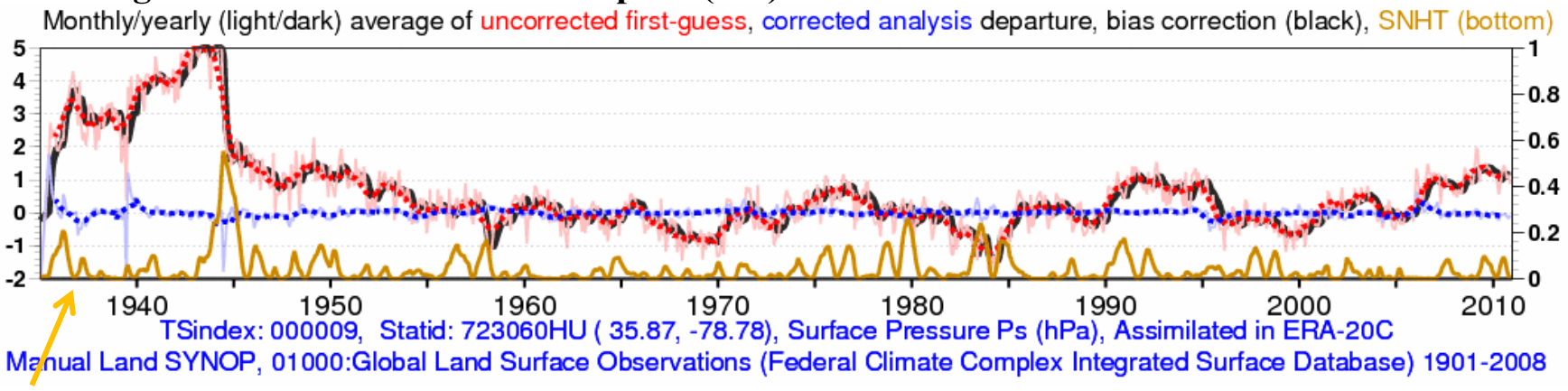
Standard Normal Homogeneity Test (SNHT)

- Used e.g., by ***Haimberger (2005)*** for homogenization of radiosonde data
- Expresses the difference in long-term average departures ***before*** and ***after*** an observation.

- Let the response time of **VarBC** depend on the history of the ***bias volatility***

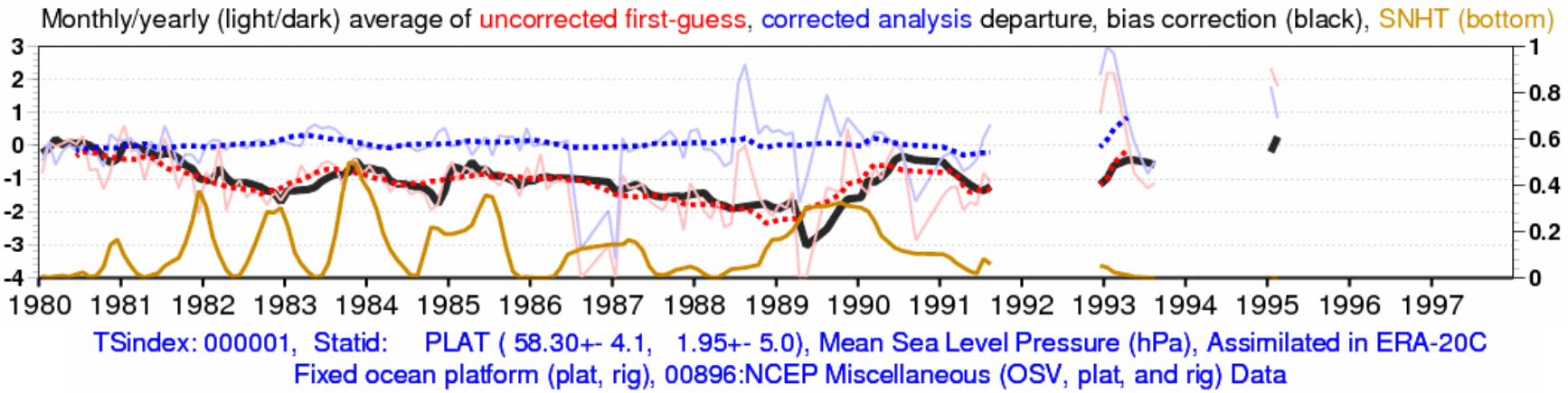
Applied VarBC in ERA-20C

Raleigh-Durham International Airport (NC)



From 20CR

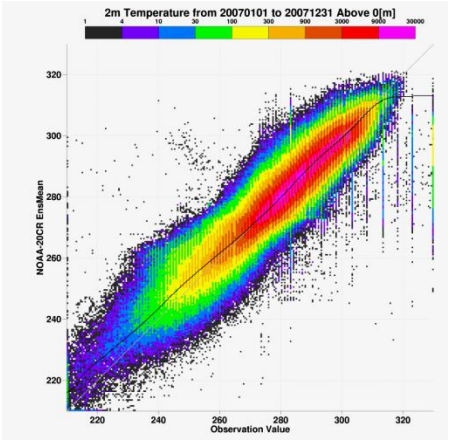
Platforms and Rigs



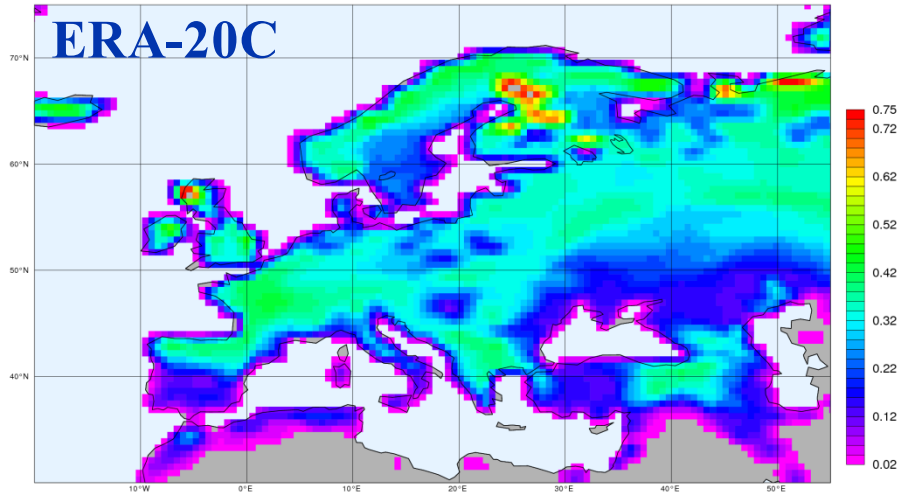
ERA-20C/Land

- Down-scaling the ERA-20C reanalysis at the surface **to 25km (T799)**
  T. Komori

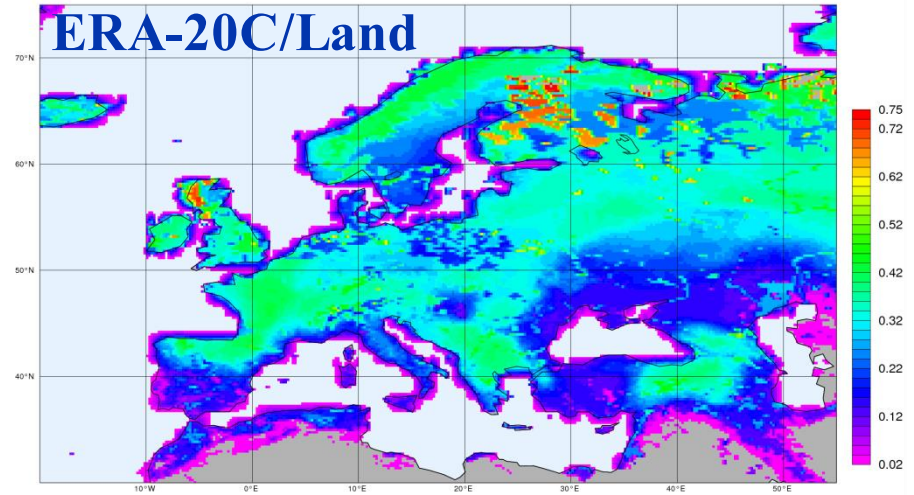
Method as used in ERA-Interim/Land
Balsamo et. al. 2012, ERA Report Series (13)



2m temperature over land versus observations



Soil moisture



ERA Pre-SAT: Usage of early upper-air data

- Deterministic reanalysis from **1939 – 1956+** demonstration run

- In addition to surface data, use ***all*** available **upper-air data**:
  - ✓ **CHUAN**, **NCAR** holdings, **ERA-CLIM** data

Joey Comeaux (NCAR)

The forecast for D-Day (June 6, 1944)

Simmons et. al. 2014, www.ecmwf.int

Chart by James Stagg, Chief Meteorologist

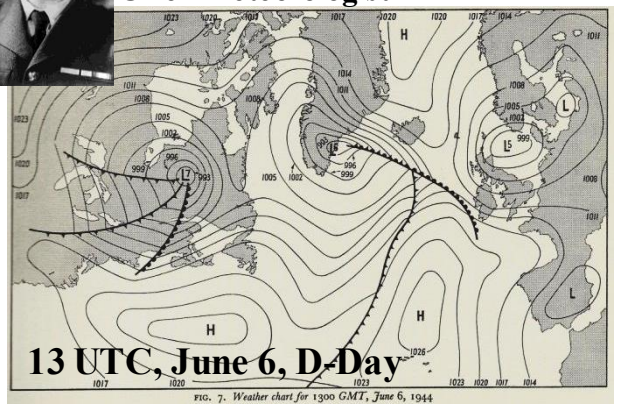
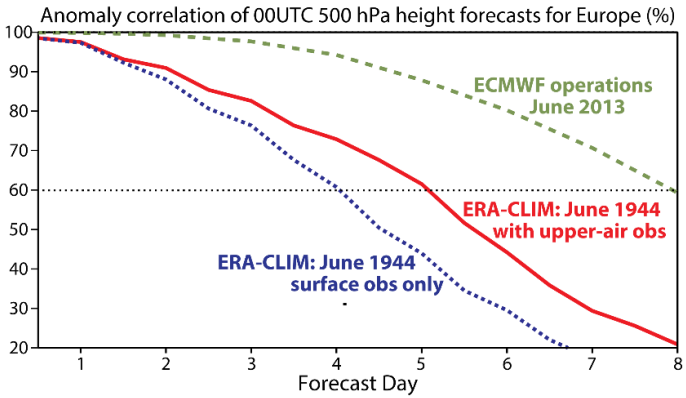
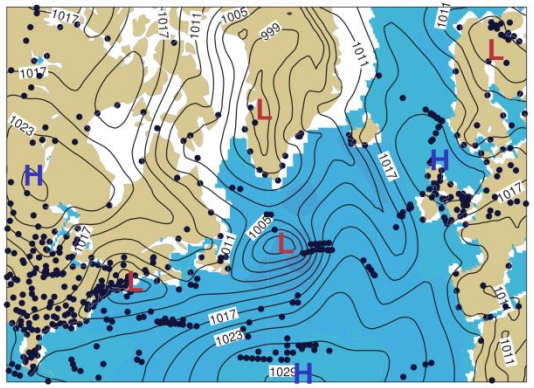


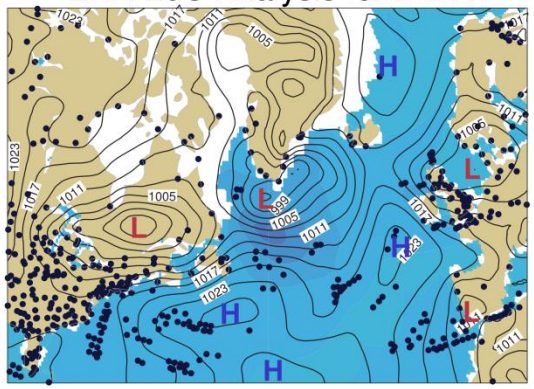
FIG. 7. *Weather chart for 1300 GMT, June 6, 1944*



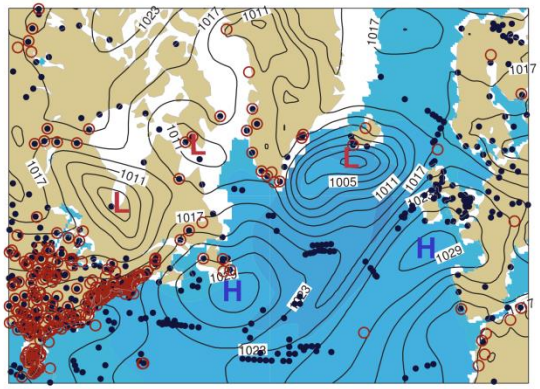
ERA-20C 108-hr forecast for D-DAY



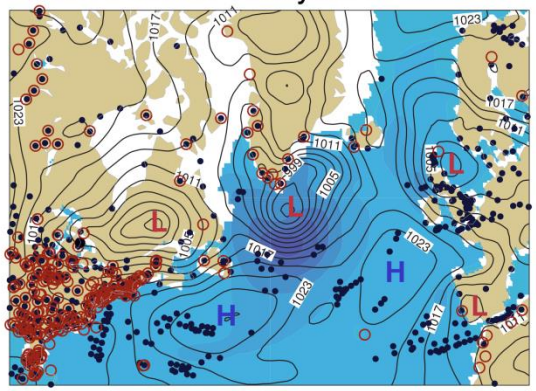
ERA-20C Analysis for D-DAY



ERA-PreSAT 108-hr forecast for D-DAY



ERA-PreSAT Analysis for D-DAY



Surface

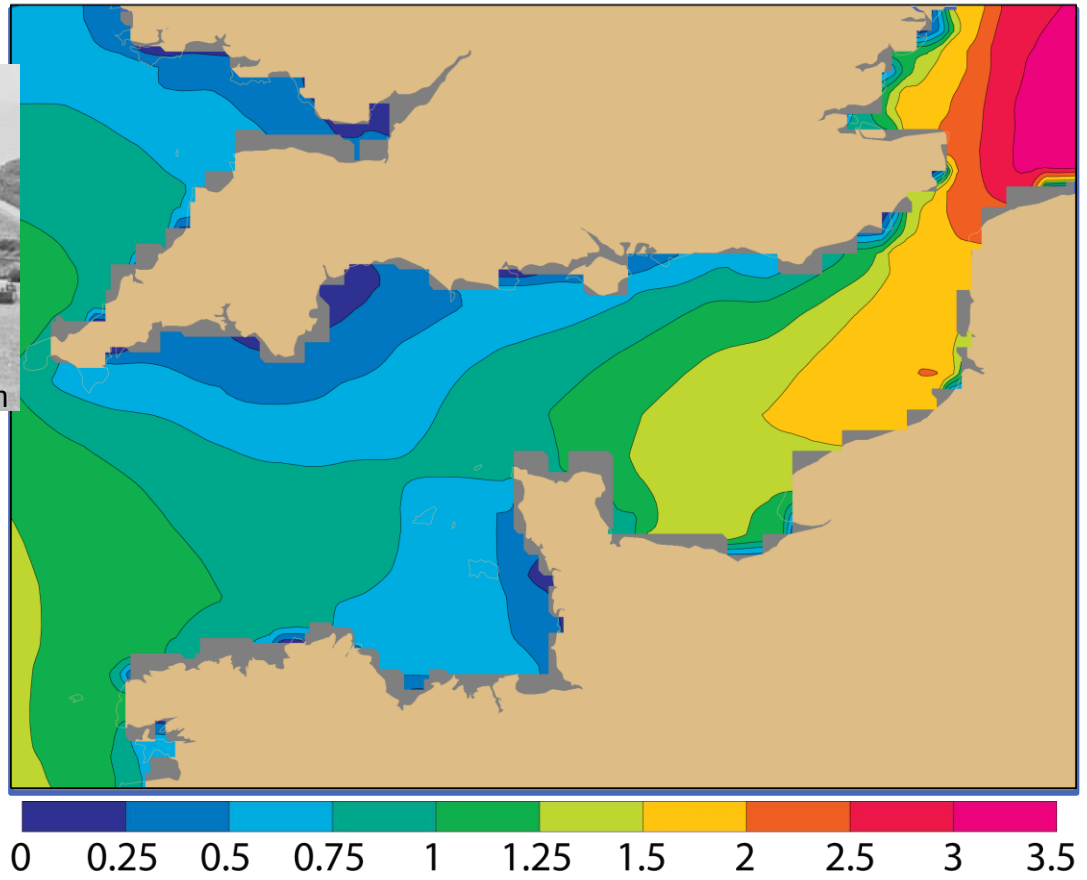
Upper air (mostly Pilot)

The storm of 19-22 June 1944

Imperial War Museum

Mulberry A

00UTC 18 June 1944 *Jean Bidlot*

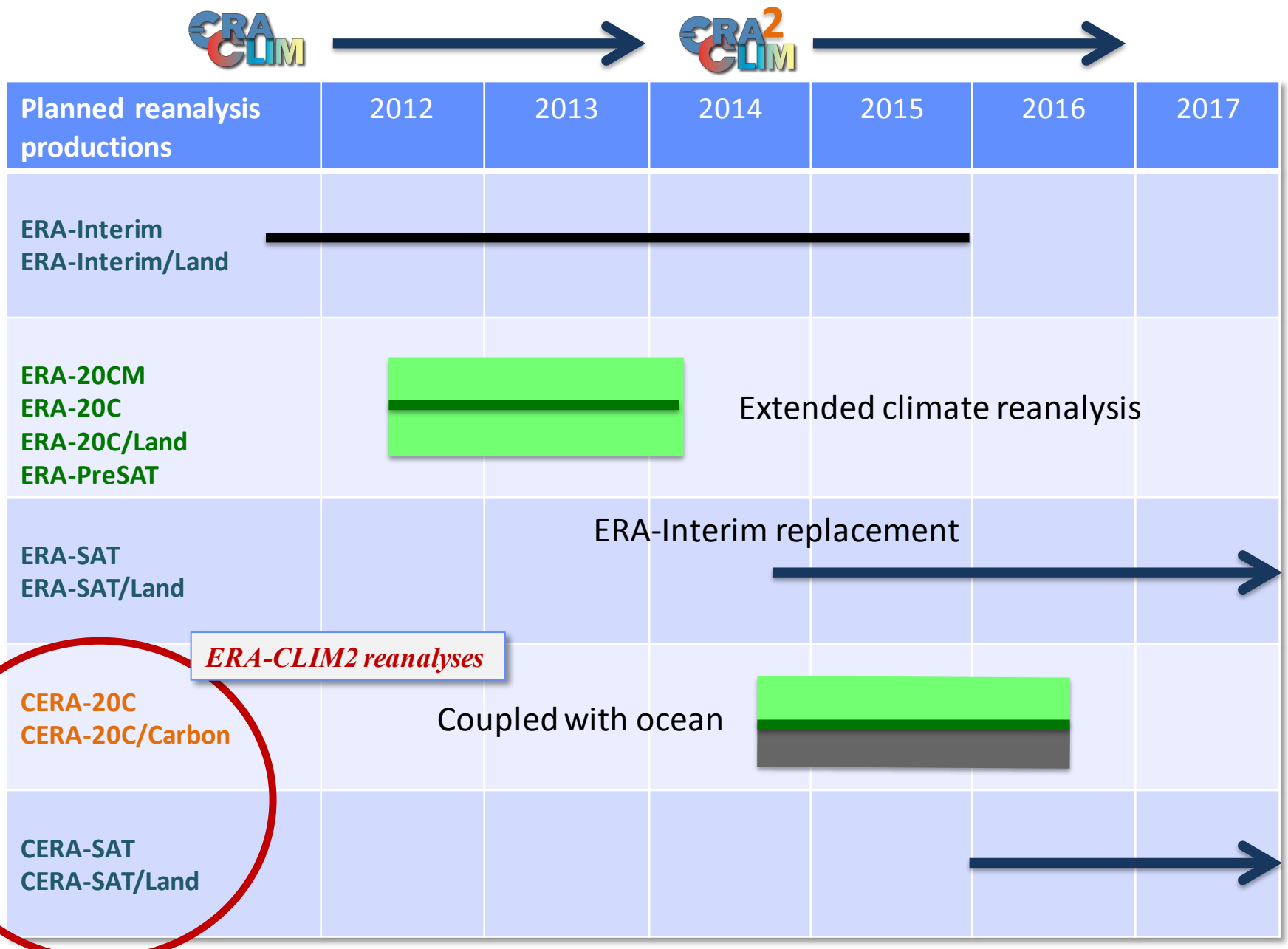


Significant wave height (metres)
from a wave model with 0.1° grid, driven by winds from successive 6h, 9h, 12h and 15h forecasts, produced 12 hourly

Extract from a US Naval Report:

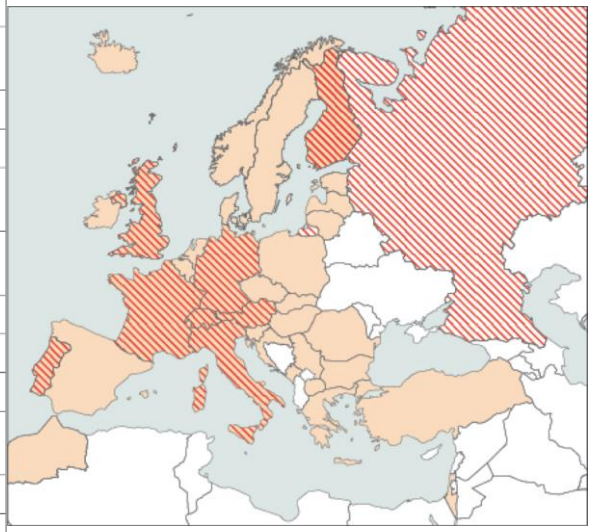
… the velocity of the wind increased to 30 knots, with wave action of eight to ten feet…

ECMWF


ERA CLIM
ERA CLIM2
Planned reanalysis productions
2012
2013
2014
2015
2016
2017
ERA-Interim
ERA-Interim/Land
ERA-20CM
ERA-20C
ERA-20C/Land
ERA-PreSAT
Extended climate reanalysis
ERA-SAT
ERA-SAT/Land
ERA-Interim replacement
ERA-CLIM2 reanalyses
CERA-20C
CERA-20C/Carbon
Coupled with ocean
CERA-SAT
CERA-SAT/Land

ERA-CLIM2 project (2014-2016)

No	Name	Short name	Country
1	EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS	ECMWF	United Kingdom
2	MET OFFICE	METO	United Kingdom
3	THE EUROPEAN ORGANISATION FOR THE EXPLOITATION OF METEOROLOGICAL SATELLITES	EUMST	Germany
4	UNIVERSITAET BERN	UBERN	Switzerland
5	UNIVERSITAET WIEN	UNIVIE	Austria
6	FUNDACAO DA FACULDADE DE CIENCIAS DA UNIVERSIDADE DE LISBOA	FFCUL	Portugal
7	ALL-RUSSIAN RESEARCH INSTITUTE OF HYDROMETEOROLOGICAL INFORMATION-WORLD DATA CENTRE	RIHMI	Russian Federation
8	MERCATOR OCEAN	MERCO	France
9	METEO-FRANCE	METFR	France
10	DEUTSCHER WETTERDIENST	DWD	Germany
11	CENTRE EUROPEEN DE RECHERCHE ET DE FORMATION AVANCEE EN CALCUL SCIENTIFIQUE	CERFAC	France
12	CENTRO EURO-MEDITERRANEO SUI CAMBIAMENTI CLIMATICI SCARL	CMCC	Italy
13	ILMATIETEEN LAITOS	FMI	Finland
14	THE UNIVERSITY OF READING	UREAD	United Kingdom
15	INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE	INRIA	France
16	UNIVERSITE DE VERSAILLES SAINT-QUENTIN-EN-YVELINES.	UVSQ	France

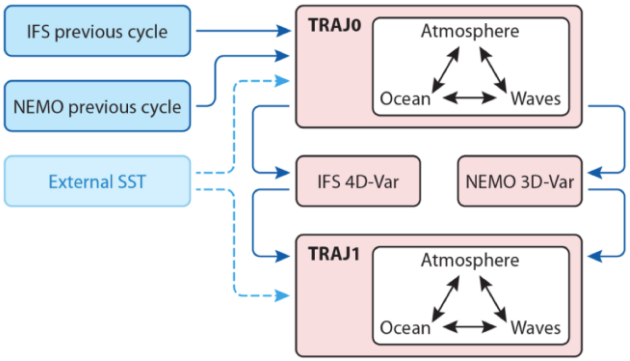


Within the EU research FP7 programme
16 partners, 88 person-years

2 International organizations
4 National Meteorological Services
5 Academic institutions
5 National research centres

ERA-CLIM2 objectives

Ensemble of ***20th-century reanalyses***, using a ***coupled atmosphere-ocean model***, ***including carbon cycle*** across these domains



Usage of a sub-surface temperature and salinity ocean dataset from ERA-CLIM (**EN-4**)

New state-of-the-art ***coupled global reanalysis of the satellite era*** at improved spatial resolution, which will provide a climate monitoring capability ***with near-real time data updates***

Continued ***improvement of observational data sets***, ***in-situ as well as satellite-based***, with a focus on temporal consistency and reliable estimates of essential climate variables

Development of tools and resources to help ***assess uncertainties in reanalysis products***

ECMWF data server

Access to reanalysis data and observation quality information

Model fields at full resolution

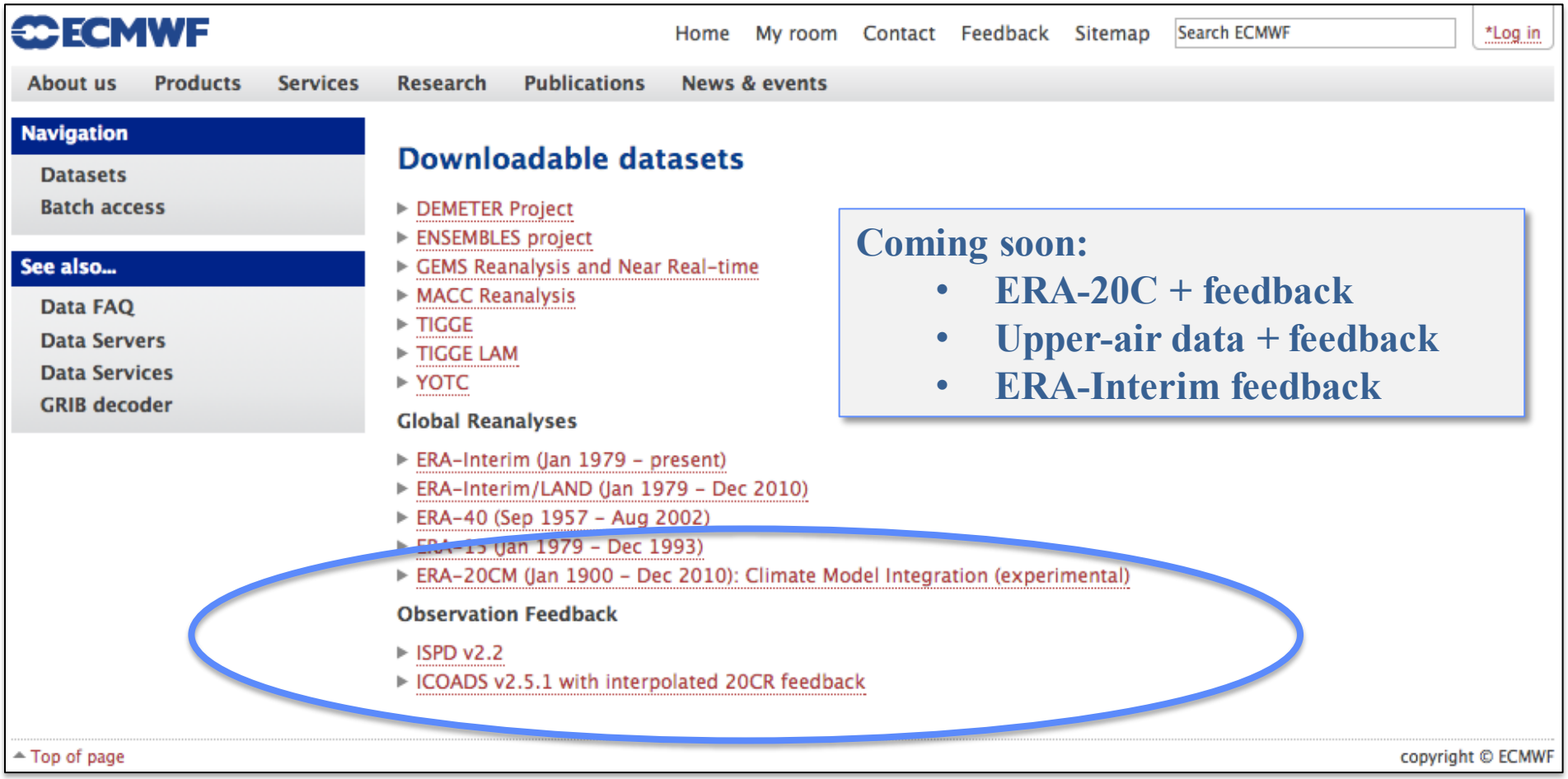
- ERA-Interim, ERA-CLIM, …

Observation feedback archive (OFA)

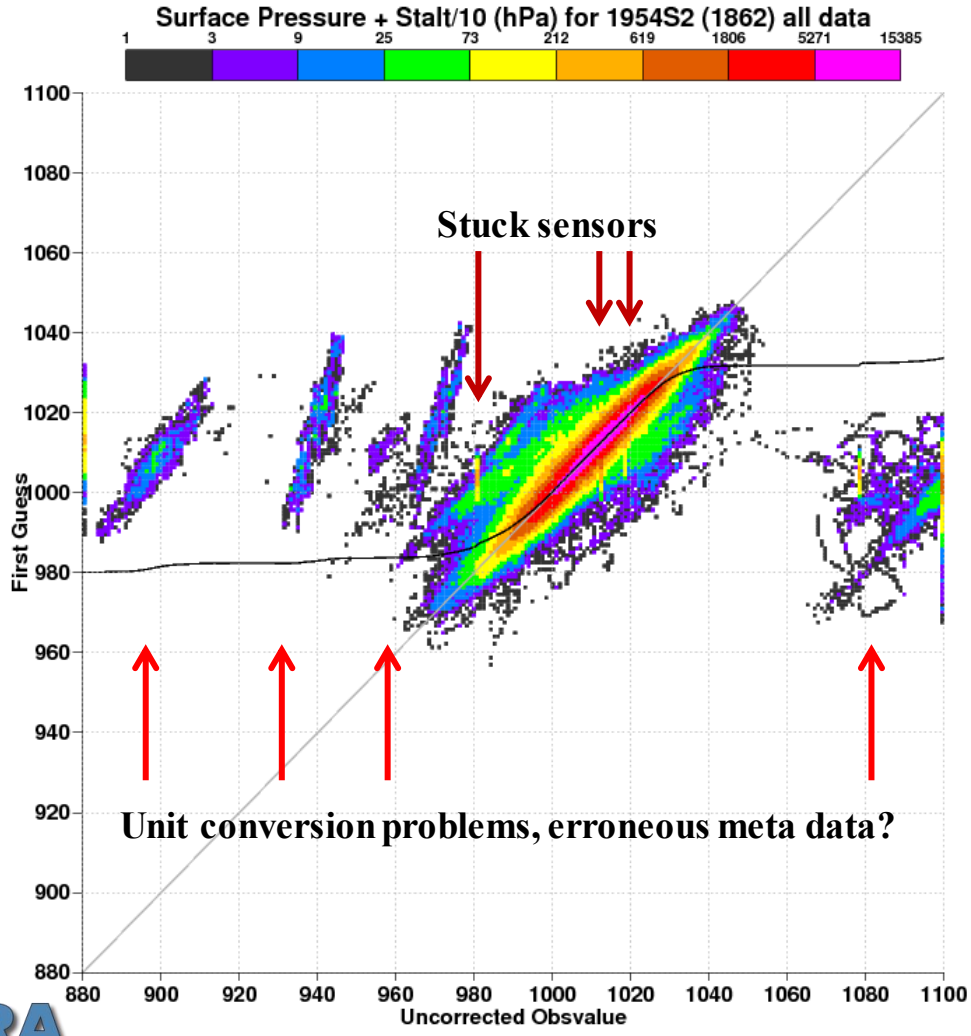
- Based on data format used at ECMWF: **ODB**
  - ✓ One row per observation, not per report
  - ✓ Is, therefore, flexible

- Contains ***valuable* feedback** information:
  Quality control, model departures, bias estimates, traceability,…

Data server at http://apps.ecmwf.int/datasets/



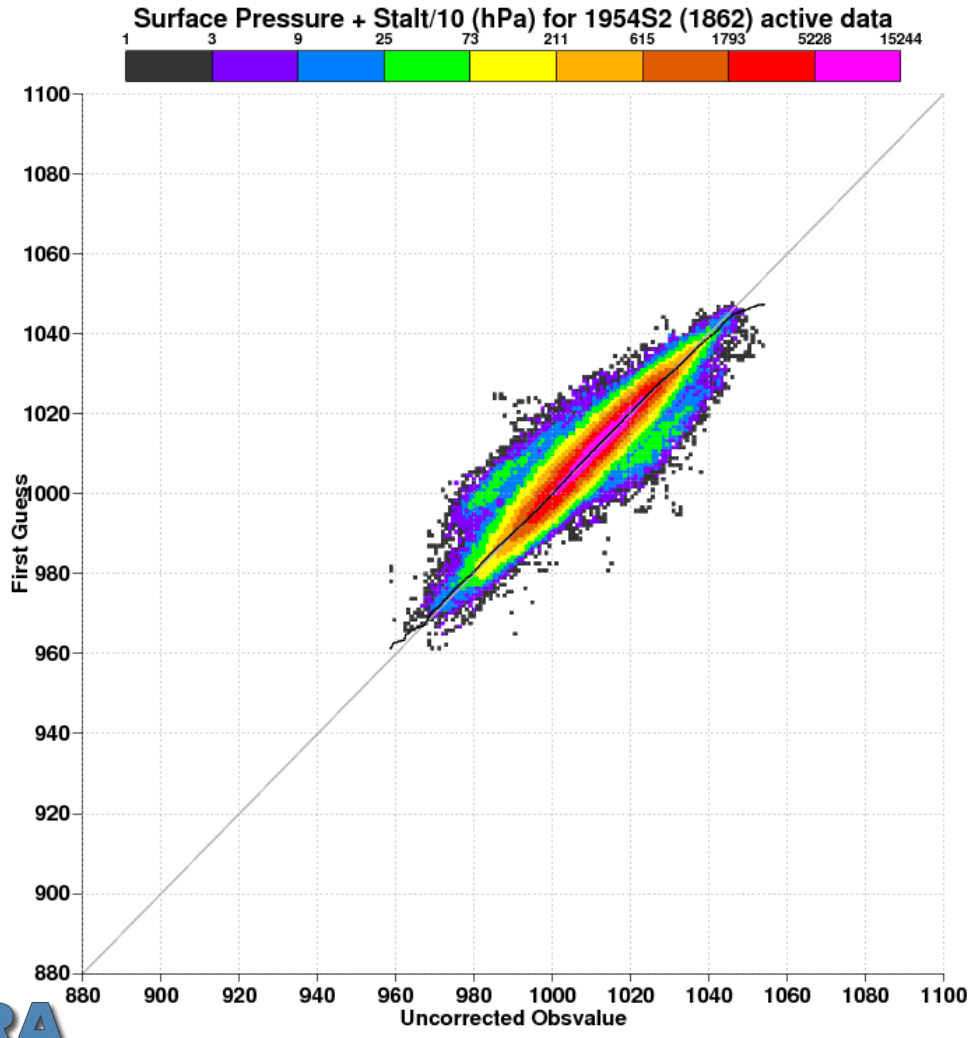
Feedback: Quality control **ERA-20C *all data***



Number of collocations:		1989418
Y-X Mean, stdv:	-0.003	15.675
X Mean, stdv:	1010.623	17.344
Y Mean, stdv:	1010.620	9.379

Feedback: Quality control

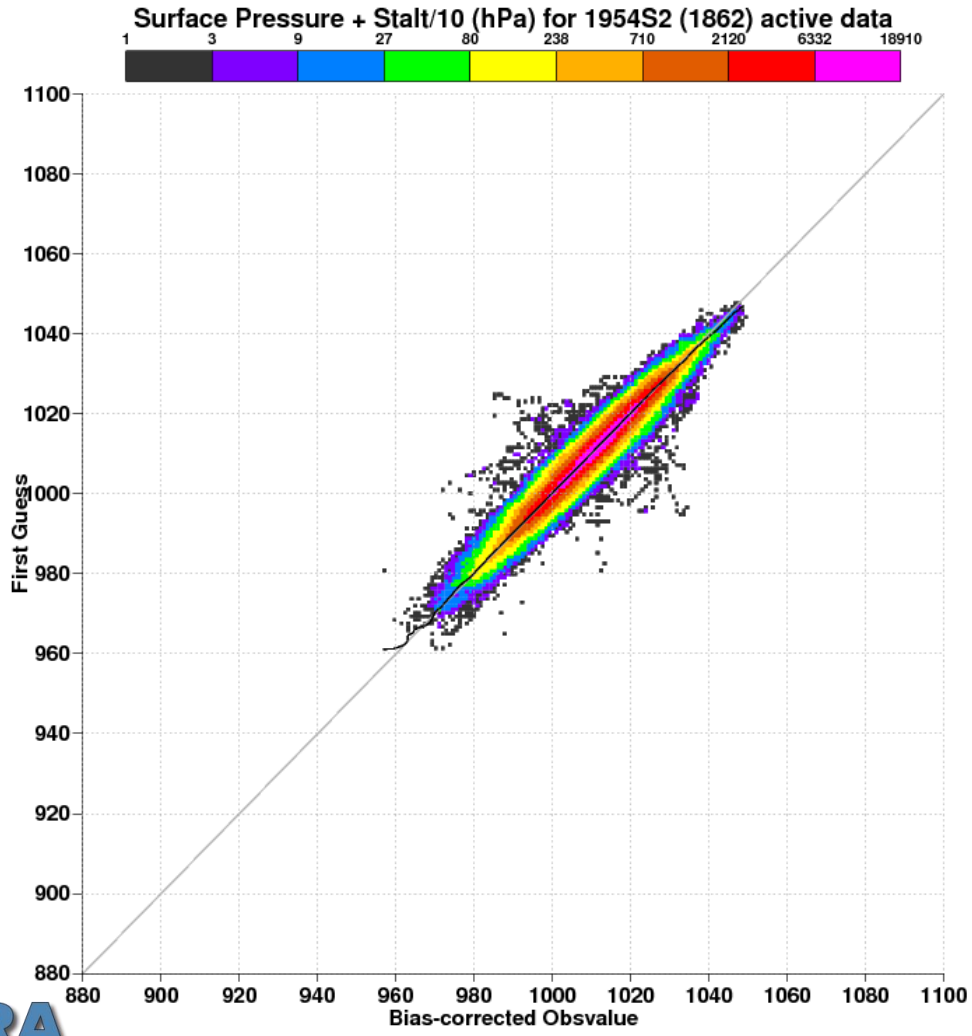
ERA-20C ***after screening***



Number of collocations:		1910905
Y-X Mean, stdv:	0.261	2.652
X Mean, stdv:	1010.466	9.303
Y Mean, stdv:	1010.728	9.364

Feedback: Quality control

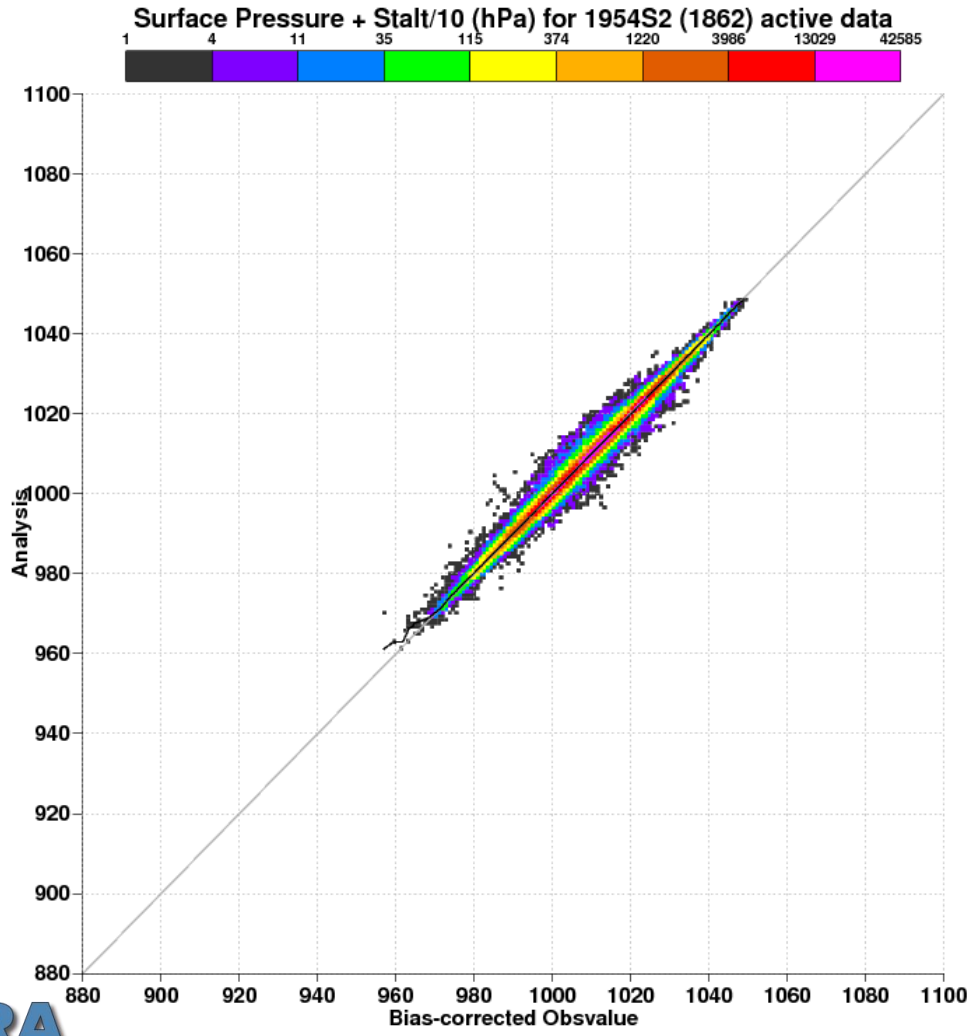
ERA-20C *Bias Correction*



Number of collocations:	1910905	
Y-X Mean, stdv:	0.172	2.001
X Mean, stdv:	1010.556	9.388
Y Mean, stdv:	1010.728	9.364

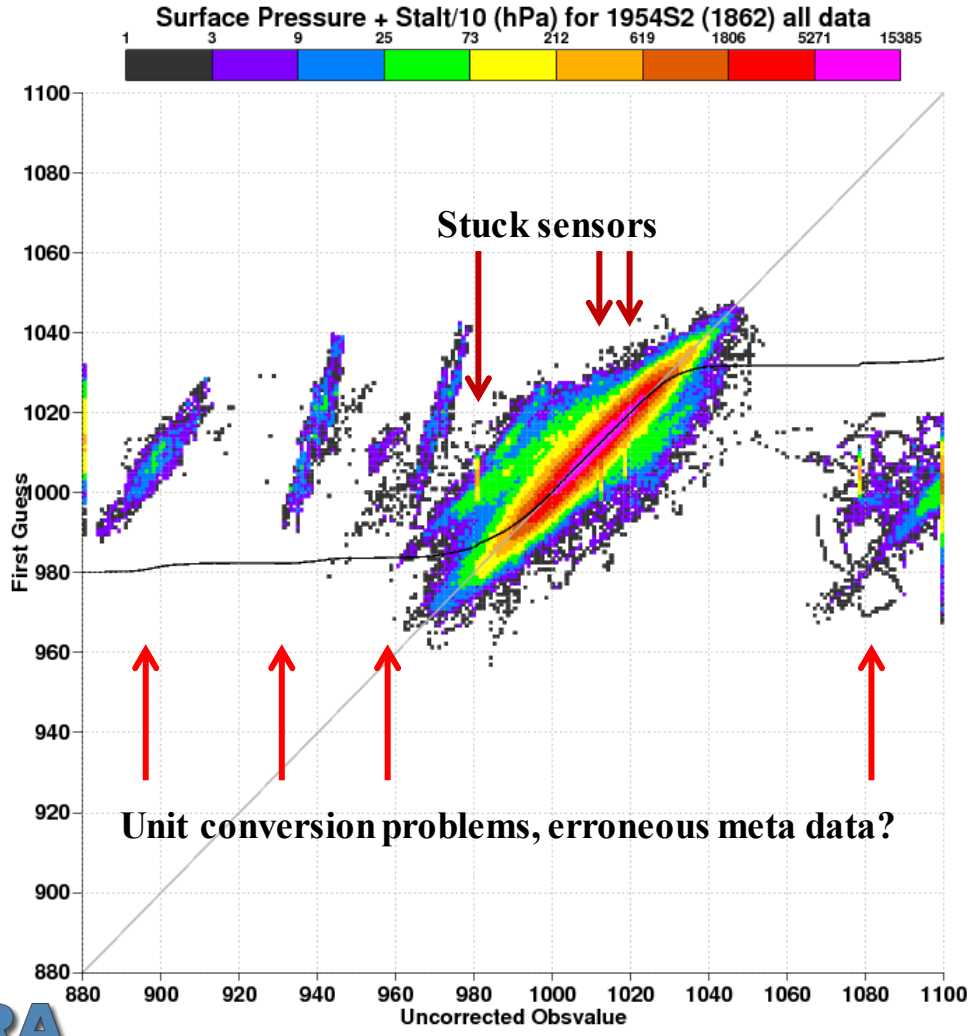
Feedback: Quality control

ERA-20C *after assimilation*



Number of collocations:	1910905	
Y-X Mean, stdv:	-0.008	0.752
X Mean, stdv:	1010.556	9.388
Y Mean, stdv:	1010.547	9.329

Feedback: Quality control **ERA-20C *all data***

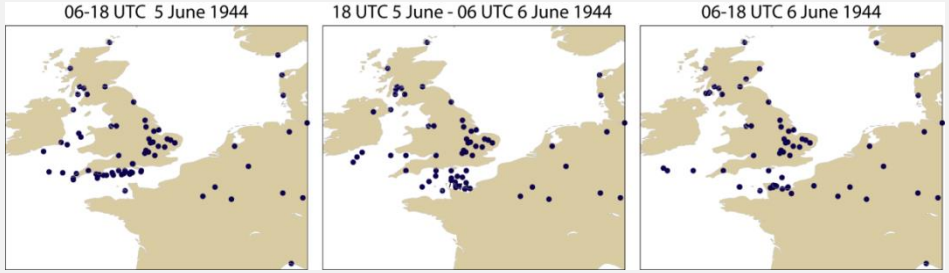


Number of collocations:		1989418
Y-X Mean, stdv:	-0.003	15.675
X Mean, stdv:	1010.623	17.344
Y Mean, stdv:	1010.620	9.379

Final remarks

ERA-CLIM has initiated a class of century-long reanalyses at ECMWF

- **Data rescue: there is still a lot out there**



- **SST, sea-ice and radiative forcing** for the entire 20th century
- Coupling with the ocean in **ERA-CLIM2**

ERA-Interim is to be replaced by **ERA-SAT**

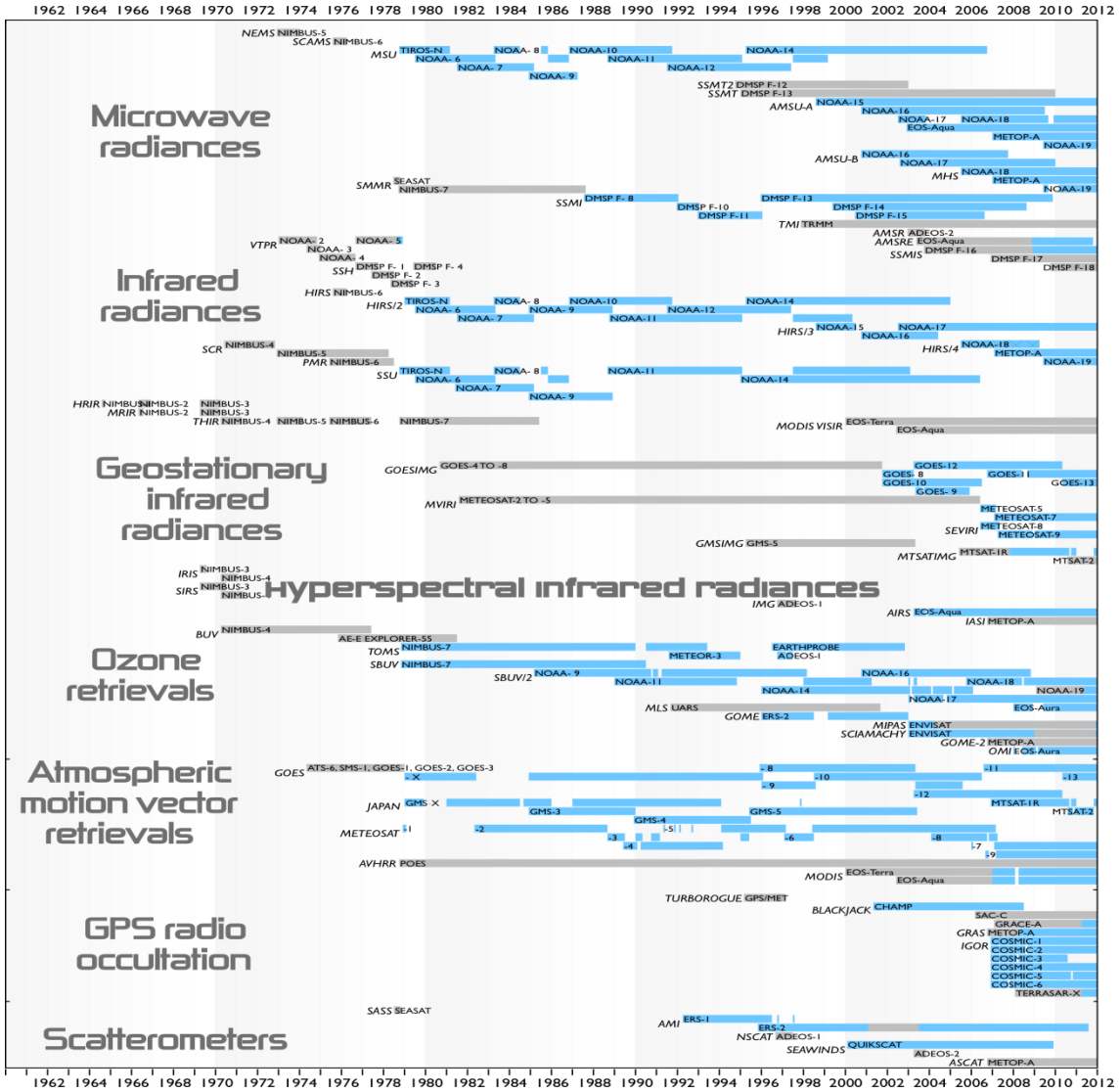
- Carries high expectations (ERA-Interim has now more than 20,000 users)
- ERA-SAT to be replaced by a ***coupled system*** in ~5 years

The ERA-CLIM reanalysis products will be freely available: ***apps.ecmwf.int/datasets/***

- Model fields, atmosphere and ocean waves
- Observation feedback archive
- ERA-Interim feedback will be made available too

It is challenging to achieve 'climate quality' with an evolving observing system in an environment of model and observation bias.

Increased satellite observation diversity



In blue: data that were assimilated in ERA-Interim

In grey: data that were not assimilated. …For future reanalyses…

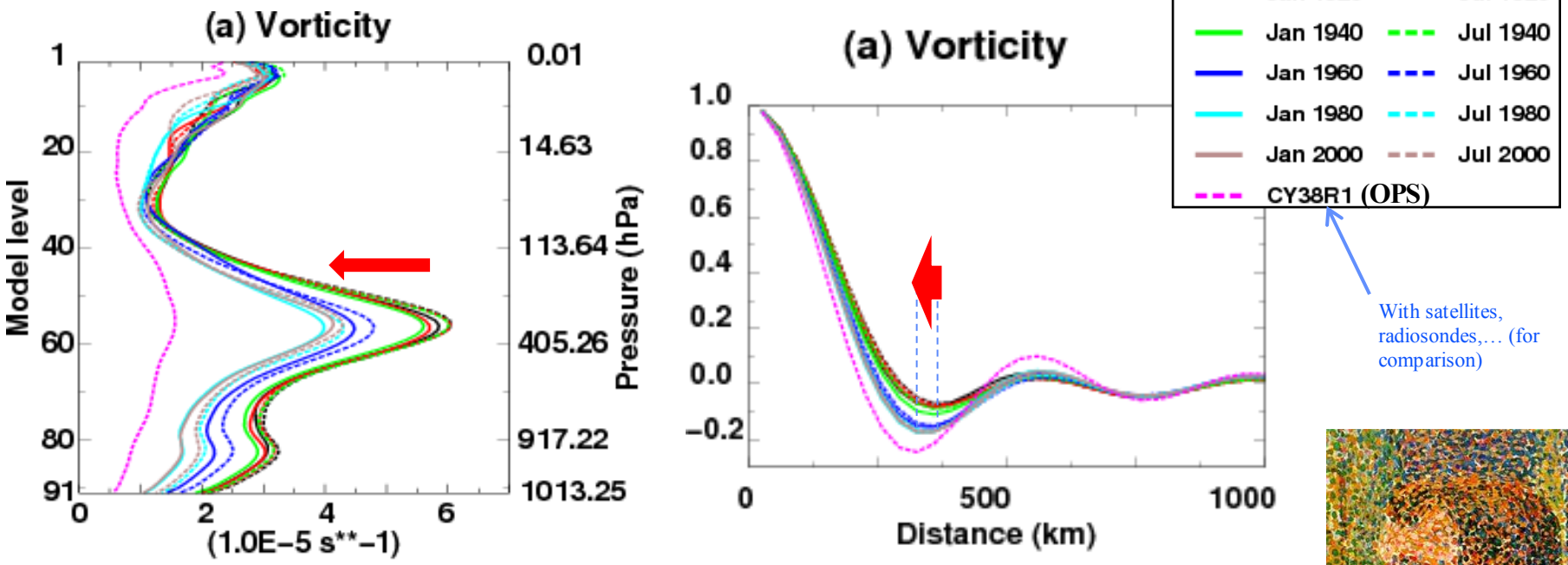
Note the timeline starts in 1969

Observation timeline (atmosphere)

ECMWF

Self-updating background error covariances, throughout the century

(updated every 10 days, based on past 90 days)



Over the course of the century, more observations result in…

➔ **Smaller** background errors, with **sharper** horizontal structures

➔ Analysis increments that are smaller, over smaller areas

= ERA-20C ensemble system adapts itself to the information available